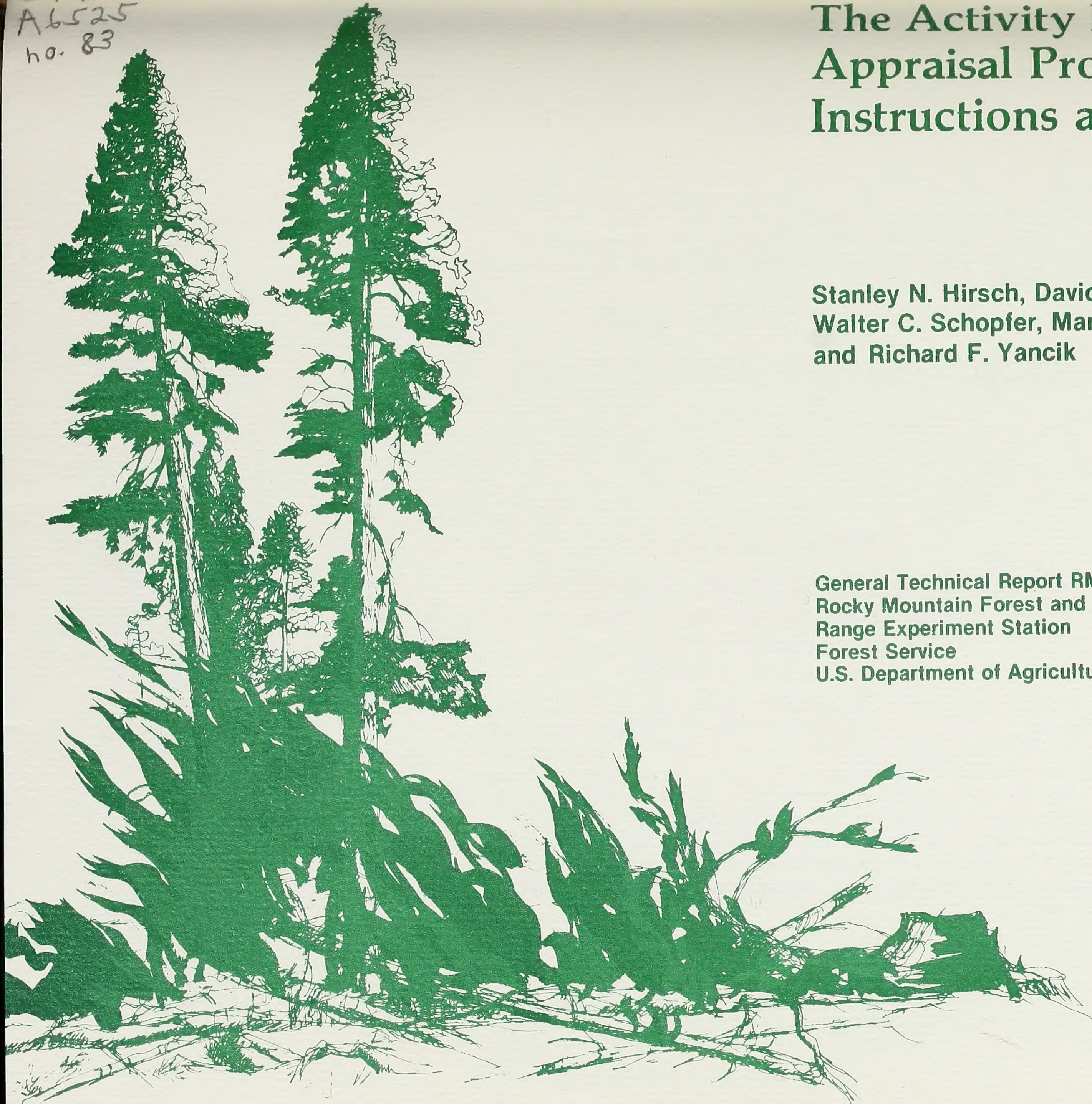

The Activity Fuel Appraisal Process: Instructions and Examples

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General Technical Report RM-83
Rocky Mountain Forest and
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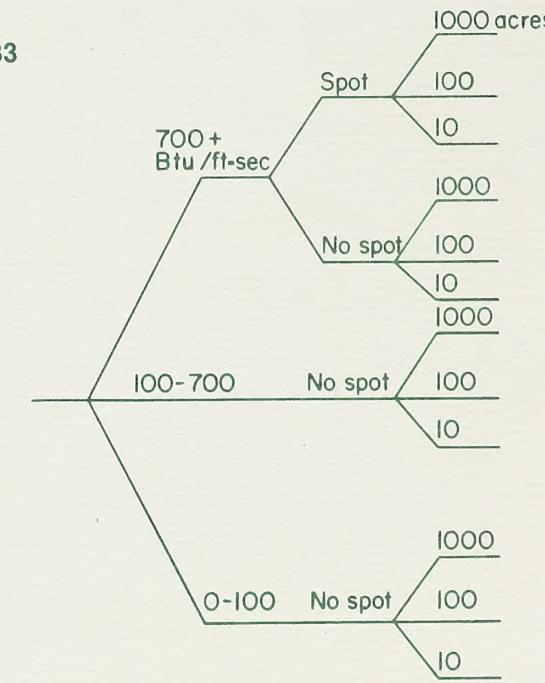

ABSTRACT

This quantitative process for appraising fire hazard from activity fuels combines fire- and fuel-modeling with decision analysis principles to produce an estimate of expected burned area. Expected fire occurrence, climate, fuel loads, fire behavior, and suppression capability are considered in the fuel appraisal process. Two case study examples are presented.

ACKNOWLEDGMENTS

The authors thank Steve Barrager of Decision Focus, Inc., Palo Alto, Calif. for his assistance throughout the development of the Activity Fuel Appraisal Process and the case studies.

The authors also thank the following USDA Forest Service personnel for their assistance during the Siskiyou National Forest case study: Dan Bender, Illinois Valley Ranger District, Siskiyou National Forest; John Dell, Regional Office, Pacific Northwest Region; Dwight Fickes, Illinois Valley Ranger District, Siskiyou National Forest; Jack Fowler, Supervisor's Office, Siskiyou National Forest; Wayne Maxwell, Pacific Northwest Forest and Range Experiment Station, retired; Ron Thames, Illinois Valley Ranger District, Siskiyou National Forest; and Bill Waterbury, Clackamas Ranger District, Mt. Hood National Forest.

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The Activity Fuel Appraisal Process: Instructions and Examples

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The Activity Fuel Appraisal Process: Instructions and Examples

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MANAGEMENT IMPLICATIONS

The Activity Fuel Appraisal Process provides a decision framework to help land managers make improved decisions concerning activity fuel management. The Activity Fuel Appraisal Process enables the manager to assess the fire hazard changes associated with fuel management actions. The manager can use the process to systematically evaluate fuel management needs and to establish fuel treatment priorities.

The Activity Fuel Appraisal Process itself is limited to use in estimating the effect of fuel treatments on subsequent fire sizes and intensities. Thus, it evaluates fuel treatments only in terms of fire hazard. To undertake a complete analysis of residue and fuel management needs, the user must add to the fire hazard aspects from the Fuel Appraisal Process other treatment costs or benefits such as wildlife habitat improvement, erosion control, esthetic enhancement, and regeneration improvement. Therefore, while the Fuel Appraisal Process does not provide the "bottom line" in analyzing alternative fuel treatments, it does provide the needed fire hazard inputs for a complete evaluation of fuel treatment needs.

INTRODUCTION

Timber harvesting and intermediate cuttings produce large quantities of combustible residue. Left untreated, this residue (activity fuels, or slash) increases fire hazard and impedes future stand management. It often interferes with wildlife and livestock grazing, blocks stream channels, and adversely affects the esthetic qualities of the site. However, residue often produces a more favorable microclimate for seedling regeneration, provides habitat for certain wildlife species, returns nutrients to the soil, and, to varying degrees, reduces erosion.

Activity fuels can be reduced through prescribed burning, mechanical crushing, and removal from the site. The costs and specific impacts of these methods differ.

The appropriate level of activity fuel treatment for a particular area depends on fuel quantities and persistence, adjacent fuel conditions, expected fire occurrence, climate, topography, fire suppression capability, treatment costs, and the effects of fire on resource outputs and land management objectives. Past practice has been for the fuel management specialist to evaluate these factors subjectively to choose a treatment. This has produced wide variation in treatments in seemingly similar fire hazard situations (McCleese et al. 1976). In order to allocate funds efficiently to fuel management activities, managers need a procedure to evaluate these factors systematically. This need will become more acute as resource management funds become more scarce and fuel treatment costs increase.

This paper describes the Activity Fuel Appraisal Process—a quantitative system for consistently weighing the important factors affecting fuel treatment decisions. The system provides a method for estimating the expected burned area resulting from wildfires starting in or burning into activity fuel. It considers the effects of slope, local climate, fire occurrence, activity fuel load, adjacent fuels, and suppression capability. The combination of fuelbed modeling, fire modeling, and decision analysis described in this paper has been useful in analyzing a variety of National Forest fuel treatment decisions. As a side benefit, the approach provides clear documentation of the decision analysis process.

This report has three major sections: The first contains background information, the second is a brief discussion of the steps in the activity fuel appraisal process, and the third contains detailed instructions for the process and two examples of its application. The examples are color coded with each step of the examples positioned beside the general discussion of that step.

The first case study describes the evaluation of ways to mitigate fire hazard from a precommercial thinning project in larch-Douglas-fir in Montana. In the second study, alternative fuel treatments are evaluated for Douglas-fir sawtimber slash in Oregon.

BACKGROUND INFORMATION

Decision Analysis

The general approach described for fuel appraisal is decision analysis—a combination of quantitative modeling and decision theory (Howard 1973). Bentley and Kaiser (1967) use decision analysis to evaluate alternative investment opportunities for Christmas tree growers. Talerico et al. (1978) illustrate the applicability of decision analysis for pest control decisions, and Fight and Bell (1977) present a conceptual discussion of decision analysis applications to timber management planning. Roussopoulos (1979) discusses the use of decision analysis for determining management needs for fuel information. The approach has been used successfully in private industry and government for decisions involving complex, dynamic, and uncertain factors.

Decision analysis is used in fuel appraisal to evaluate alternative fuel management strategies in the face of uncertainties about future fire occurrence, weather, fire behavior, and fire size.

An important concept in decision analysis is "expected value," a probability-weighted average of all possible outcomes. Some examples will help illustrate this concept.

Imagine that you are given the opportunity to play a game: a fair coin will be tossed, and if the head side lands up you will receive $1. For a tail you receive $0.10. Unfortunately, you must pay $0.60 to play the game. You are now faced with making a decision—should you play or not?

This situation is represented in the decision tree shown in figure 1. The tree shows decision alternatives and the probabilities of the possible outcomes. The probabilities and outcome values make it possible to numerically evaluate the decision alternatives.

The node marked with a square is a decision node. Each branch from this node describes a decision alternative. If you choose the top branch (Not play), you pay nothing, but you receive nothing. If you choose the bottom branch (Play), you pay a cost of $0.60, but the outcome is uncertain. Therefore, the "Play" branch leads to another node—a probability node (marked with a circle). From this point, two outcomes are possible—heads or tails. Because the coin is fair, each outcome has a 0.5 probability (50% chance) of occurring. The probabilities are indicated in parentheses in figure 1.

Now you can calculate the expected outcome of playing the game. The expected outcome is the sum of the products of outcome probabilities and outcome values. As shown in figure 1, the expected outcome is $0.55. Because the cost of playing is $0.60, the net expected value of playing is $-0.05. In other words, if you played this game many times you should expect your losses to average a nickel for each time you played. Your most reasonable action, therefore, is to not play, because its expected value of $0 exceeds the expected value of playing ($-0.05). The expected value concept makes it possible to compare these decision alternatives in terms of single values.

The structure of a hypothetical fuel treatment example is illustrated in figure 2. In this example, the decision alternatives are to apply a fuel treatment at a cost of $500, or do nothing. The number of fires in the area affected by the treatment and the size of the fires is uncertain. The possible outcomes are again denoted by branches from the probability nodes (circles) in the decision tree. Suppose the probability of having a fire in the area is 0.1 over a period equal to the effective life of the treatment; also assume that probability is not affected by the treatment (it is the same on both the upper and lower branches). If there is a fire, it will burn from 1 to 1,000 acres. Treating the fuel does not guarantee protection against a 1,000-acre fire, but it does lower the probability of such a fire. On the other hand, even with no treatment, the fire might be held to 1 acre. The uncertainty about fire size is reflected in the probabilities assigned to each size class. The effect of treatment is to change these probabilities.

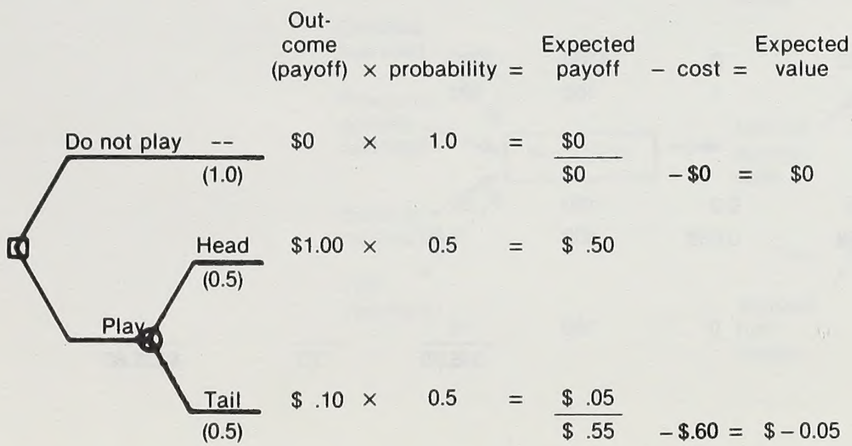


Figure 1.—Decision tree of the coin toss problem. The box represents a decision node. The circle represents a probability node. The numbers in parentheses following the probability node are event probabilities.

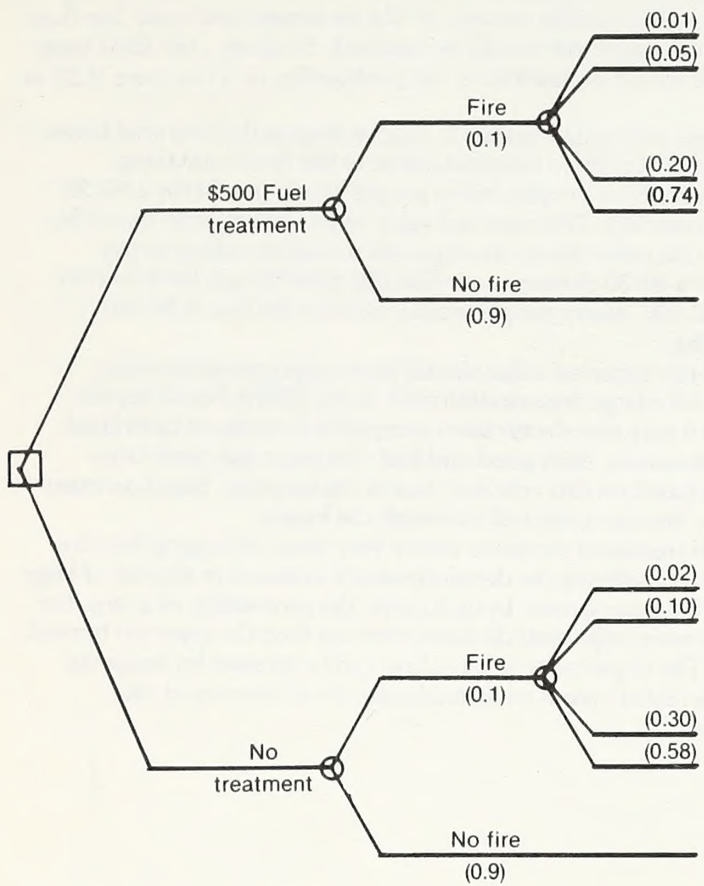
The cost and probability of each outcome are tabulated to the right of the tree in figure 2. For this example the fire-related costs (including suppression and net resource damage) are assumed to be $100 per burned acre.

The problem of the fuel manager in this example is to choose the action which minimizes the combined treatment costs and fire losses. The expected cost of each alternative is calculated by multiplying the cost of each outcome by its probability and summing the products over all possible outcomes. In this case, the loss expected after treatment is only $177.40, compared with $335.80 without treatment. However, the $500 treatment cost increases the total cost plus loss of the treatment to $677.40 Thus, the treatment does not lower expected losses enough to justify its cost. If the treatment cost were less than $158.40, the treatment would be justified. Similarly, the $500 treatment cost would be justified if the probability of a fire were 0.32 or greater.

The expected value criterion is valid as long as the potential losses are not large enough to be catastrophic to the decisionmaking organization. For example, many people would pay $4 for a 50/50 chance to win $10. The expected value of this lottery is $5 minus $4, or $1. On the other hand, fewer people would be willing to pay $4,000 for a 50/50 chance to win $10,000 even though the expected value is $1,000. Many people would consider the loss of $4,000 catastrophic.

In general, expected value should be an appropriate decision criterion for a large organization such as the USDA Forest Service, although it may not always seem acceptable in terms of individual, isolated decisions. Both good and bad outcomes can result from decisions based on this criterion, but in the long run, based on many decisions, average gains will outweigh the losses.

For fuel treatment decisions where very large, damaging fires are involved, considering the decisionmaker's aversion to the risk of large fires may be appropriate. In such cases, the probability of a large fire may be a more important decision criterion than the expected burned acreage. The importance of large fires can be stressed by assigning very high costs to them when analyzing the economics of fuel treatments.



Outcome (Fire size in acres)	× probability =	Expected burn (acres)	× Fire costs per acre =	Expected fire costs	+ Treatment cost ($500) =	Expected cost plus loss (or expected value)
1000	0.001	1	$100	$100		
100	0.005	0.5	100	50		
10	0.020	0.2	100	20		
1	0.074	0.074	100	7.40		
0	0.9	0	100	0		
				177.40	$500	$677.40
1000	0.002	2	$100	$200		
100	0.01	1	100	100		
10	0.03	0.3	100	30		
1	0.058	0.058	100	5.80		
0	0.9	0	100	0		
				335.80	$0	$335.80

Figure 2.—Decision tree for a hypothetical fuel treatment decision. Treatment cost is $500 and fire-related costs total $100 per acre.

Data Needs for Fuel Appraisal

The Activity Fuel Appraisal Process is summarized diagrammatically in figure 3. Data are derived from several sources. Weather and fire occurrence data are obtained from historic records. Activity fuels are uniquely modeled from stand inventories, cutting prescriptions, and dead and down woody fuel inventories. Natural fuels and treated activity fuels are represented by stylized fuel models. The fuel and weather inputs are processed through a fire behavior computer program to produce estimates of fireline intensity—the rate of heat release along the fireline. The effect of suppression capability on final fire size is accounted for by questioning local fire control personnel to determine the chance of containing a fire under specified burning conditions.

The fire occurrence, fire behavior, and fire size data are combined in a decision tree (fig. 4) to determine total expected annual burned area and expected annual burned area by fire size and intensity class. The probabilities (p_i), fire size outcomes (s_j), and annual fire occurrence rate (r) must be input by the user. Expected burned area is derived by multiplying probabilities and the fire size outcomes along each branch and summing for all outcomes. For the tree in figure 4, expected burned area per fire (E) is

$$E = (p_1 \times p_4 \times p_6 \times s_1) + (p_1 \times p_4 \times p_7 \times s_2) + \ldots + (p_3 \times p_{24} \times s_4) + (p_3 \times p_{25} \times s_5).$$

Expected annual burned area is $r \times E$. Decision trees are constructed and evaluated for each activity fuel treatment. The results are compared to determine the relative effectiveness of the treatments.

This paper explains how to obtain the required numerical inputs to a decision tree.

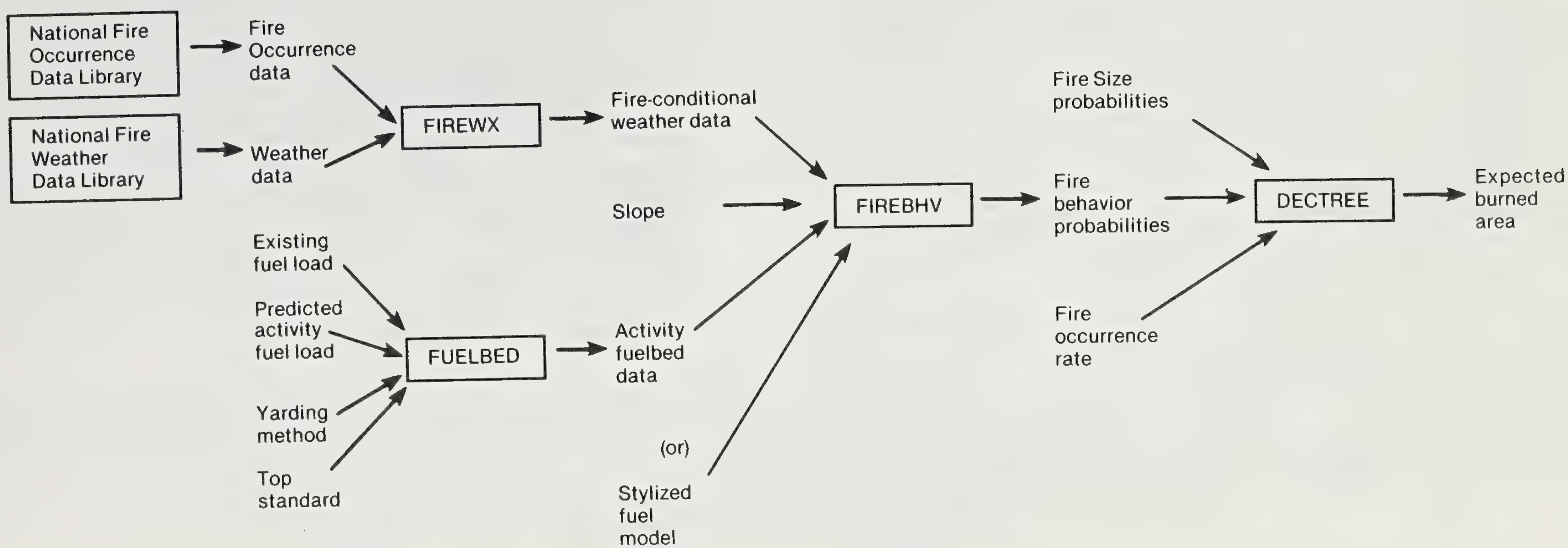


Figure 3.—Generalized diagram of the Activity Fuel Appraisal Process. The boxes represent computer programs and data libraries used in the process. Programs FUELBED, FIREWX, FIREBHV, and DECTREE are discussed in the text.

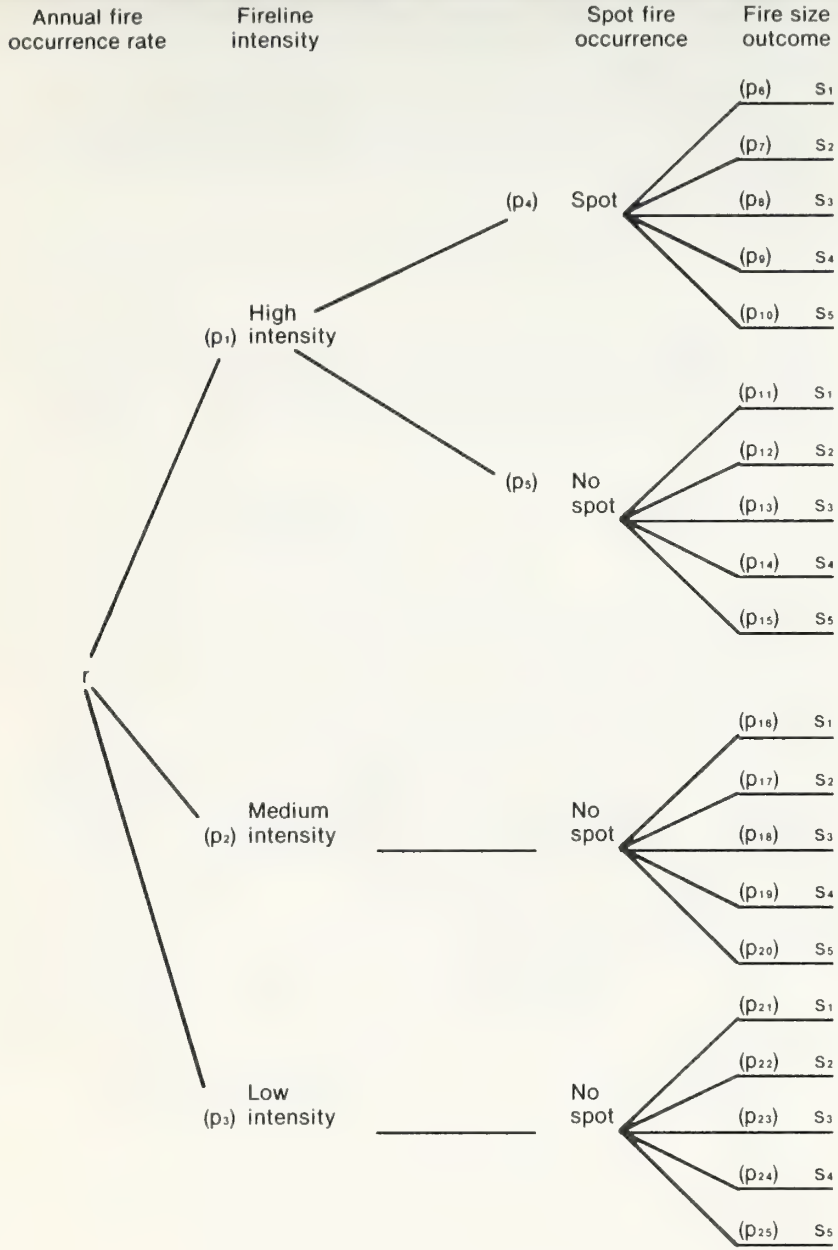


Figure 4.—A general decision tree for fuel treatment analysis. This tree is used to estimate expected burned area for a specific fuel situation.

Fire Occurrence

Past records provide the best means for estimating the fire occurrence rate in an area. Records of individual fires are maintained in a magnetic tape library at the USDA Fort Collins Computer Center (Roussopoulos et al. 1980). Other agencies maintain similar records on computer files. These records can be accessed to determine the annual fire occurrence rate for an administrative unit. This rate can be prorated over the desired area. If future fire occurrence rate is expected to change, the historical rate can be adjusted.

Fire Behavior

If a fire occurs, the expected fire behavior depends on weather conditions, topography, and fuels. Rothermel (1972) developed a mathematical fire behavior model which makes it possible to estimate fire behavior over a wide range of these influencing factors.

Rothermel's model estimates the forward rate of spread and the intensity at the actively flaming front of a "steady-state" fire. Spotting, erratic flame movement, or other "special" types of behavior are not considered. Input parameters for the model include:

Ovendry fuel loading (pounds per square foot)
Surface-area-to-volume ratio (square feet per cubic foot)
Total mineral content (pounds minerals per pound fuel)
Silica-free mineral content (pounds minerals per pound fuel)
Heat value (Btu per pound)
Ovendry particle density (pounds per cubic foot)
Moisture of extinction (percent)
Fuel depth (feet)
Fuel moisture (percent)
Topographic slope (percent)
Wind speed at midflame (feet per minute).

Collectively, the first eight parameters constitute a fuel model—a numerical description of a specific fuel situation. The last three parameters specify weather and physiographic conditions that influence fire behavior.

In order to use decision analysis in evaluating fuel treatments, fuel models are needed that represent treated and untreated activity fuels as well as surrounding natural fuels.

Stylized fuel models adequately represent natural fuel conditions from grass to brush to closed timber. Guidelines assist the user in selecting the appropriate models for specific regions of the country.

Site-specific fuel models can be constructed for activity fuels in any forest stand. The computer program FUELBED uses stand table data, a cutting prescription, and individual tree weight data to describe the resulting fuelbed 1, 3, and 5 years after cutting. The model can reflect the effects of different logging methods and treatment of the slash by lopping. The output from FUELBED includes all the fuelbed parameters required by the Rothermel model.

The required weather inputs (wind speed and fuel moisture) come from the National Fire Weather Data Library (Furman and Brink 1975). Because fires are not equally likely to occur on all days during the fire season, weather data are selected conditional on past fire occurrence as recorded in the National Fire Occurrence Data Library (Roussopoulos et al. 1980). This is accomplished by computer program FIREWX.

The computer program FIREBHV processes Rothermel's fire model for any fuel model for all fire-conditional weather data and constructs a probability distribution of fireline intensity. The fireline intensity probabilities are shown as p_1, p_2, and p_3 in figure 4.

FIREBHV also estimates the spotting probabilities, p_4 and p_5, shown in the next node of the decision tree (fig. 4). These probabilities are based on the judgements of forest fire scientists[3] that significant spotting is likely when wind speed is $\geq$10 miles per hour, fuel moisture is $\leq$10%, and fireline intensity is $\geq$700 Btu per foot per second.

[3]*Personal communication with Rod Norum, Institute of Northern Forestry, Fairbanks, Alaska, formerly of the Northern Forest Fire Laboratory, Missoula, Mont.*

Fire Size

There is no general simulation capability to model the size at which a fire will be controlled. Therefore, the judgement of fire managers is used to construct fire scenarios and assign probabilities to various fire size outcomes for each intensity and spotting situation (p_6 through p_{25} in fig. 4). A procedure for quantifying expert judgement is described in detail in the next section.

THE ACTIVITY FUEL APPRAISAL PROCESS

Overview

The Activity Fuel Appraisal Process consists of five analysis activities: defining the problem, fuel modeling, modeling fire behavior, estimating fire size, and estimating expected burned area. The process is summarized below and described in detail in the following sections.

Figures 5 through 8 illustrate the role of each step in the Activity Fuel Appraisal Process.

Defining the Problem

Step 1: Establish boundaries of area to be included in the analysis. This will often be a drainage.

Step 2: Obtain present and projected stand data and a cutting prescription for the area.

Step 3: Define the fuel treatment alternatives to be evaluated.

Step 4: Obtain historical fire records for the analysis area or a surrounding area with similar fire history. (Several years of fire records are needed.)

Step 5: Obtain historical weather data for the fire weather station which best represents conditions in the analysis area.

Fuel Modeling

Step 6: Select stylized fuel models representing the natural fuels in the analysis area.

Step 7: Develop site-specific activity fuel models to represent the activity fuelbeds.

Step 8: Modify the activity fuel models or select other stylized models to reflect fuel treatment effects.

Modeling Fire Behavior

Step 9: Merge the fire records and weather records (selected in steps 4 and 5) to produce a weather data file for days on which fires have occurred. Using these fire-conditional weather data, run the fire behavior model for each fuel model selected in steps 6, 7, and 8.

Estimating Fire Size

Step 10: Define a set of possible final fire size classes.

Step 11: Assign occurrence probabilities to all fire size classes.

Estimating Expected Burned Area

Step 12: Evaluate a decision tree for each fuel treatment.

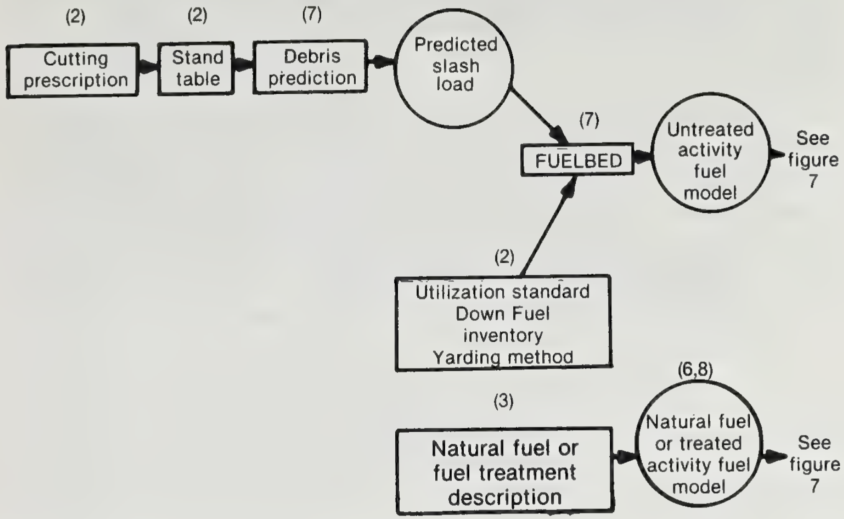


Figure 5.—Fuel modeling steps in the fuel appraisal process. Different procedures are used for activity and natural fuels. Activity fuel models are developed through the FUELBED computer model; natural fuel models (and treated fuelbeds) are selected from stylized fuel models. Numbers in parentheses refer to steps in the Activity Fuel Appraisal Process.

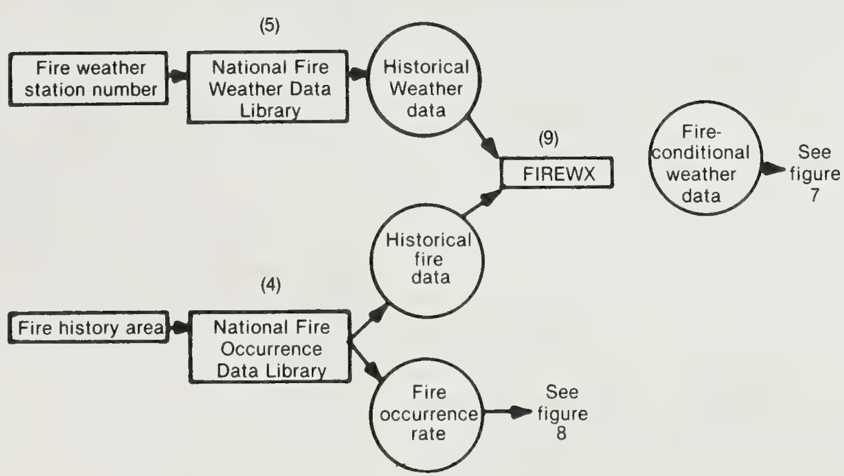


Figure 6.—Weather and fire data are obtained from computerized data libraries. Numbers in parentheses refer to steps in the Activity Fuel Appraisal Process.

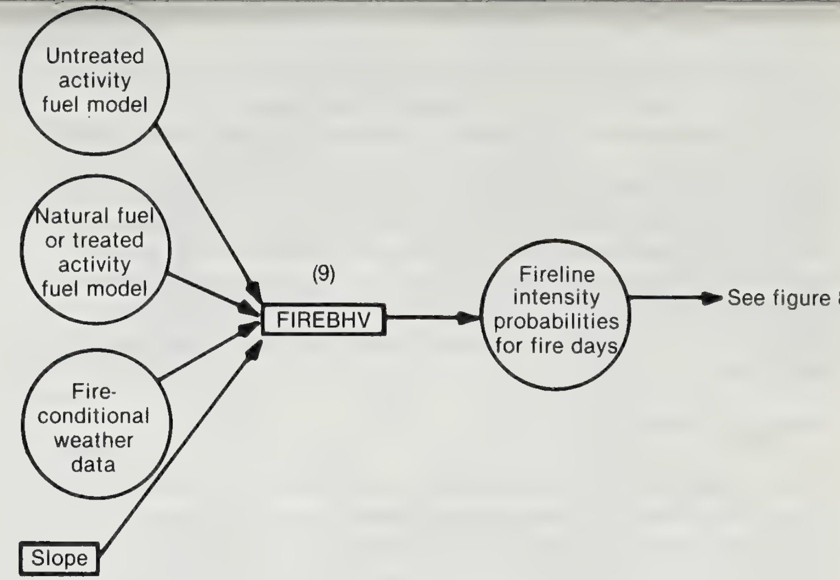


Figure 7.—Fuels, weather, and topographic information are combined in the fire behavior model FIREBHV. Numbers in parentheses refer to steps in the Activity Fuel Appraisal Process.

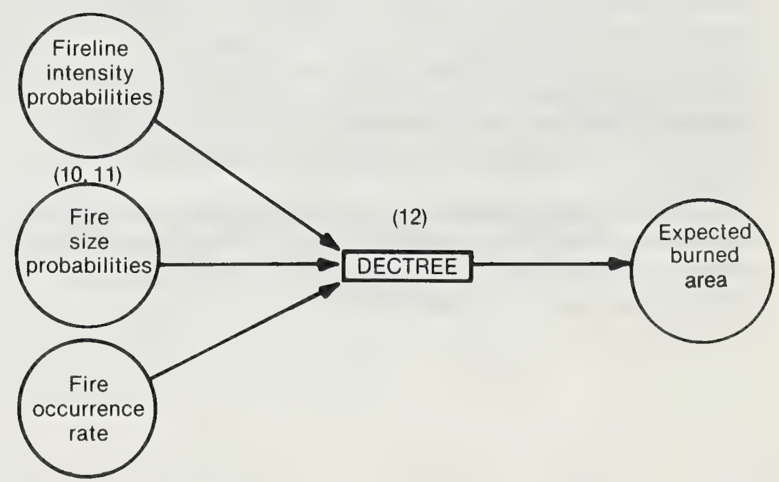


Figure 8.—A decision tree program DECTREE computes expected burned acreage. Expert opinion is used to provide fire size probabilities. Numbers in parentheses refer to steps in the Activity Fuel Appraisal Process.

INSTRUCTIONS AND EXAMPLES

The instructions for the activity fuel appraisal process are given in the following pages, with two examples of the application of each step. The instructions for each step are in black type, beginning in the leftmost column of each double-page spread. An example of the application of each step on the Flathead National Forest (Montana) is printed in green to the right of the instructions. A similar example from the Siskiyou National Forest (Oregon) is printed in blue to the right of the Flathead example. In cases where the number and size of figures preclude inclusion of all the instructions and examples for a step on a double-page spread, the examples continue onto a second or third spread.

Defining the Problem

Step 1: Establish Boundaries of the Analysis Area.—The analysis area should include not only the activity fuel area, but also adjacent areas which could influence or be influenced by fires in the activity area. Usually the boundaries will correspond to a well defined drainage or a designated "pre-attack block." The final determiners are normal work unit planning convenience and homogeniety of fuels and fire history. To help determine the boundaries of the analysis area, ask the question "Under extreme conditions, where might a fire burn if it starts in the slash? What type of burning pattern could result?"

Future management actions which would result in additional activity fuels must also be addressed when designating this boundary. Timber harvesting, cultural activities such as thinning or release, or other slash-producing management activities can significantly alter the overall fire hazard. It will often be useful to include units with similar future management plans in the same analysis area.

Because the results of the activity fuel analysis will be affected by the scope of the designated analysis area and the management alternatives chosen for it, much thought and consideration are needed in making this boundary decision.

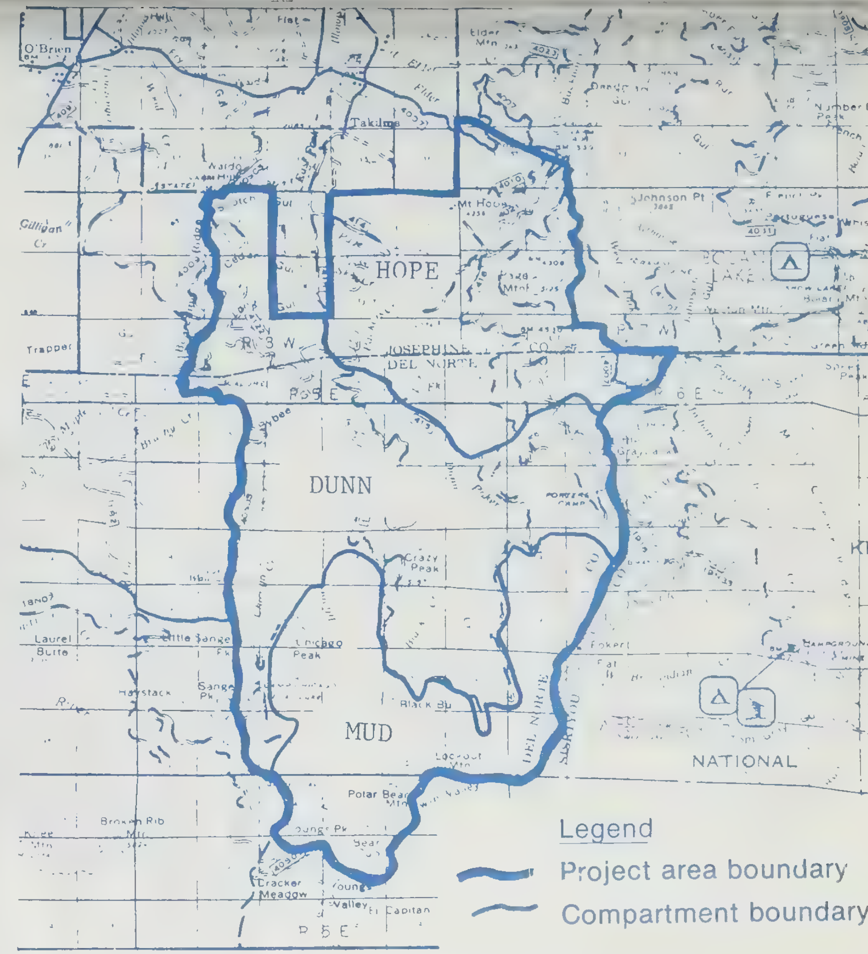
Flathead Step 1.—Hungry Horse District of the Flathead National Forest plans to thin 2,100 acres of a 10,000-acre stand of larch (*Larix occidentalis* Nutt.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) on Fire Fighter Mountain near Hungry Horse, Mont. Three units, each about 700 acres, will be thinned. Slopes average about 30%.

Continuous slash in 700-acre units is unacceptable because of the large-fire potential it represents. Therefore, the units will be thinned in smaller blocks, separated by uncut strips. Continuous crowning fires have not occurred in the project area and persistant high winds are rare, so the uncut strips will provide a buffer of low fire hazard between cut blocks. The width of the strips and the size of the blocks have not been determined.

Siskiyou Step 1.—The Illinois Valley District of the Siskiyou National Forest harvests timber on a sustained yield basis in a 35,200-acre watershed in the headwaters of the Illinois River in Oregon and California (Siskiyou fig. 1). Elevations in the watershed range from 2,000 to more than 6,000 feet; topography is rugged with an average slope of about 50%.

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the main timber species harvested in the area. Harvest volumes in old growth stands range from 30,000 to 60,000 board feet per acre. Approximately 100 acres per year are harvested within the study area. This harvesting schedule is expected to continue.

The vegetation and cutting history of the 35,200-acre study area are not homogeneous. To enable considering homogeneous areas, three compartments were identified which differed from each other in fire hazard characteristics—the Hope, Dunn, and Mud compartments (Siskiyou fig. 1). Most timber cutting has been concentrated in the Hope compartment, and future harvesting also will be predominantly in that compartment. The Dunn compartment has had little cutting activity. The Mud compartment has not been entered for harvesting, and it probably will not be cut in the near future.



Siskiyou figure 1.—The upper Illinois River drainage was selected as the Siskiyou National Forest fuel appraisal case study area.

Step 2: Obtain Stand Data and Silvicultural Prescription.—Current and projected stand conditions and cutting prescriptions must be specified so fuel quantities can be predicted. A representative stand table listing the total trees per acre by diameter classes and species for areas to be harvested or thinned is essential. The same information must be listed for trees to be cut. If more than one silvicultural treatment is being considered for a stand, each prescription should be specified.

The required data for a hypothetical ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stand are shown below:

D.b.h.	Ponderosa pine Before cutting	To be cut
inches	-------- *trees per acre* --------	
1	100	50
4	100	50
6	100	25
10	70	35
12	50	38
16	30	30
Total	450	228

The merchantable top standard is 6 inches. This stand will be referred to throughout this section.

If the long term effects of fuel treatments are to be evaluated, expected changes in the fuel conditions of the analysis area must be specified. A simple model describing vegetation and fuel change with time is sufficient. Figure 9 illustrates an example of vegetation change and possible related fuel models.

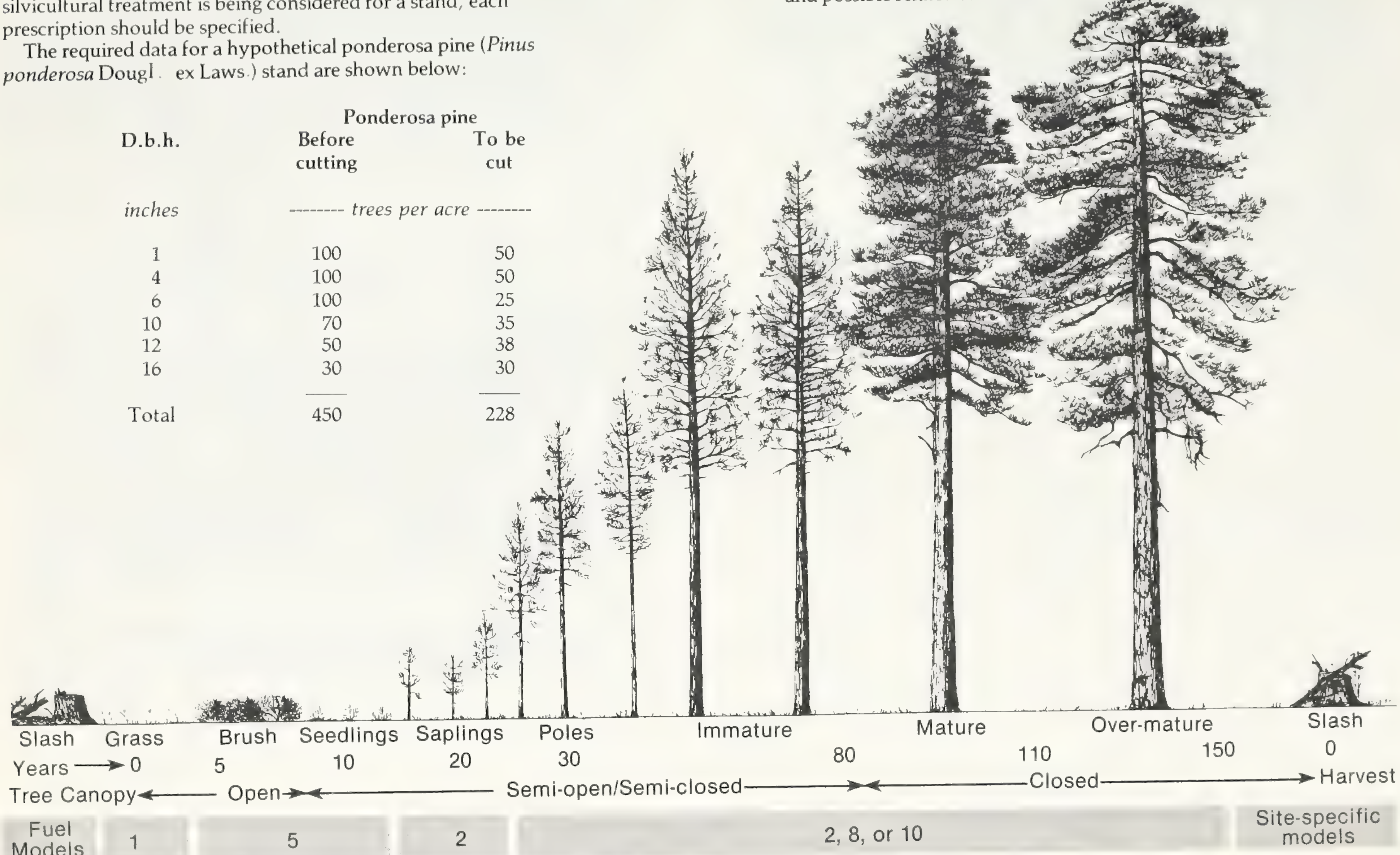


Figure 9.—Diagram of stand changes that may occur following harvest. Fuel models that may be applicable to each phase of stand development are indicated. Numbers refer to the "fire behavior" fuel models (Albini 1976a). Specific models are suggested for illustration only. The actual models most appropriate for a stand will vary with the area being considered.

Flathead Step 2.—The present density of spruce (*Picea engelmannii* Perry ex Engelm.) on Fire Fighter Mountain is shown below:

D.b.h. class	Spruce	Species Douglas-fir	Larch
inches		*stems per acre*	
1 to 3	1,000	1,100	--
3 to 4	--	--	1,050
4 to 5	--	--	1,050

The silvicultural prescription calls for a residual stand of about 200 stems per acre. All the spruce will be cut. One hundred stems per acre each of Douglas-fir and larch will be left to form the residual stand.

Siskiyou Step 2.—Timber is harvested from 100 acres in the drainage annually. In a typical Douglas-fir stand the number of trees cut per acre is 7 stems in the 10-inch d.b.h. class, 20 stems in the 22-inch class, and 68 stems in the 29-inch class.

To consider future effects of cutting activities, a fuel dynamics model was developed to approximate the fire hazard changes during the development of a stand. Four distinct phases of stand development are described in terms of their fuel characteristics: old growth, slash, brush, and second growth.

The old growth phase has the lowest fire hazard. However, future management will prevent the re-establishment of old growth stands on harvested sites.

For 5 years after harvest, a stand is characterized by fresh slash. Left untreated, this fuel results in the most intense fire behavior.

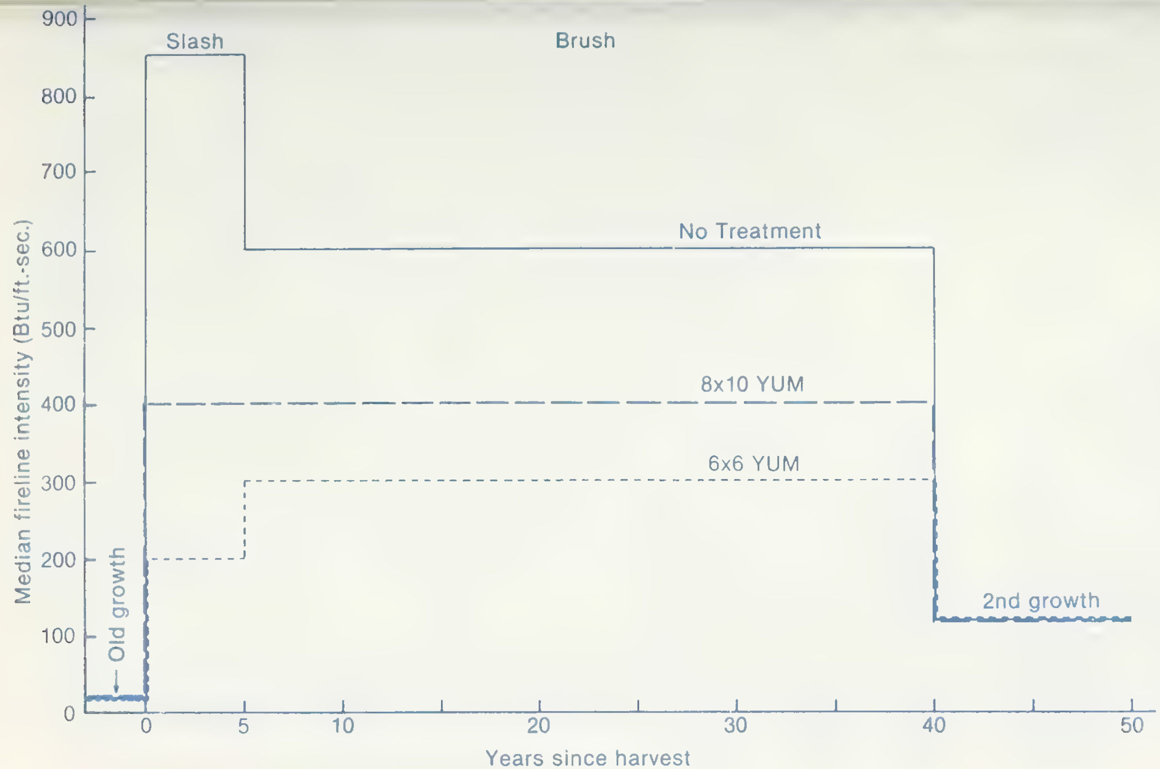
The fire behavior during the early development of a new stand is most influenced by the presence of brush. The brush fuel phase persists from the 5th to 40th year.

After 40 years, the second growth dominates the brush. The fire hazard decreases, but it is still greater than in the old growth stands.

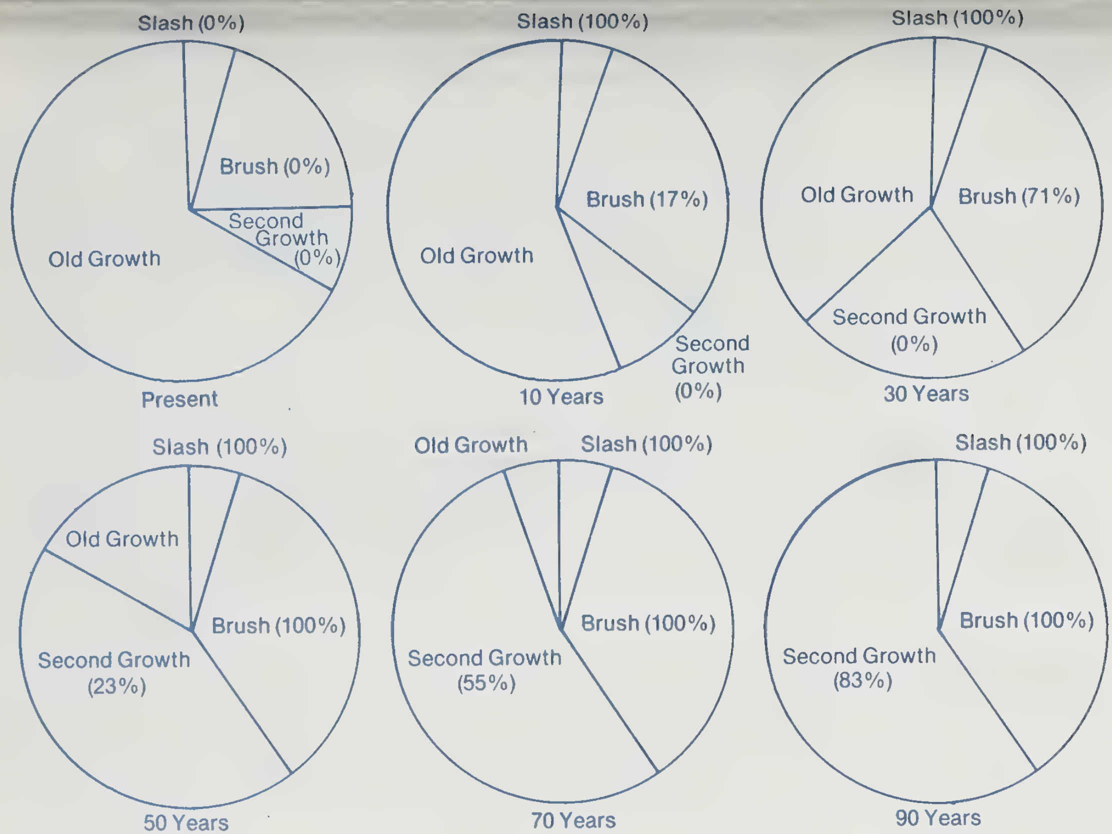
Siskiyou figure 2 shows the fire behavior trends represented by this stand model.

The composition of the study area was projected into the future to reflect expected changes in fuel conditions. Siskiyou figure 3 shows the Hope compartment composition at present and projected for 90 years. This was done only with the Hope compartment because most cutting will occur there.

The analysis considered the fuels in the Dunn and Mud compartments as static. Because of this assumption, fire hazard estimates for the Dunn and Mud compartments are constant.



Siskiyou figure 2.—Fuel dynamics of a stand in the case study area. Median fireline intensities are plotted for the no treatment case and the 8 x 10 and 6 x 6 YUM treatments. The magnitude of the "slash" fireline intensity is influenced by the amount of activity fuel and the type of fuel treatment applied. The magnitude of the "brush" fireline intensity is also influenced by prior activity fuel treatments. "Second Growth" fire behavior does not reflect any intensity effects due to residual activity fuels. However, all three stand phases after cutting will exhibit resistance-to-control differences because of fuel treatment activities.



Siskiyou figure 3.—Present and projected forest fuel structure of the Hope compartment. The numbers in parentheses indicate the percent of a fuel type which has received treatment.

Step 3: Define Fuel Treatment Alternatives.—A variety of treatment alternatives are available for use by the land manager after a management activity such as timber harvesting. These alternatives include lopping, yarding unmerchantable material, piling, piling and burning, and broadcast burning. Feasible alternatives may vary by region or locality, and should be specified for evaluation. Doing no treatment may often be a feasible alternative.

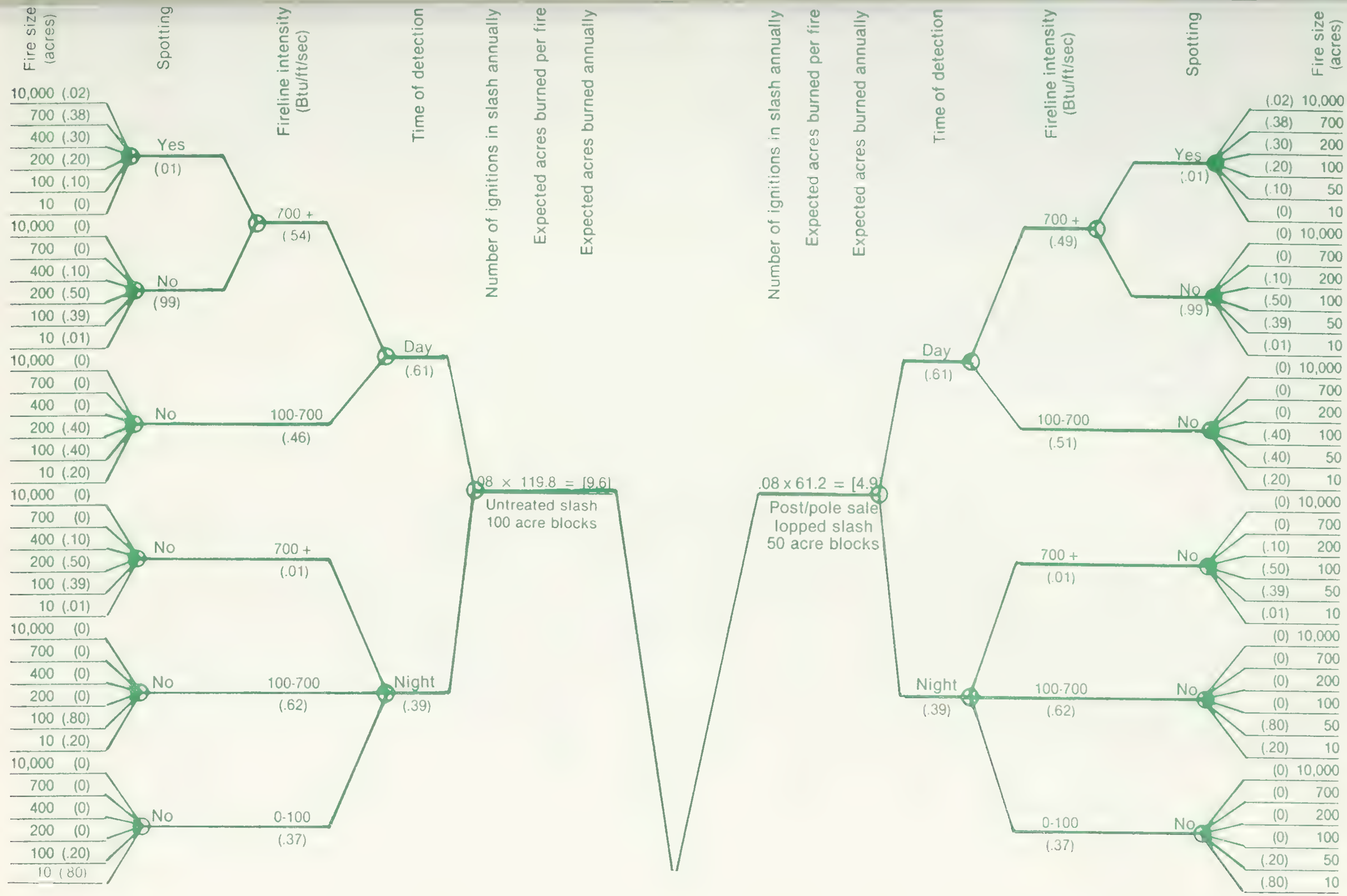
Flathead Step 3.—A fuel management plan must be selected to provide protection to the thinned stand commensurate with costs. Four alternatives are being considered by District personnel: (1) thinning in 50-acre blocks; (2) thinning in 100-acre blocks; (3) lopping slash in the 50-acre blocks to a 2-foot standard depth; and (4) removing post-pole material in the 50-acre blocks. Mechanical crushing of the slash was not considered because the steep slopes (greater than 30%) preclude using heavy machinery.

Flathead figure 1 (pages 18 and 19) is a decision tree which summarizes the Fire Fighter Mountain fuel treatment problem.

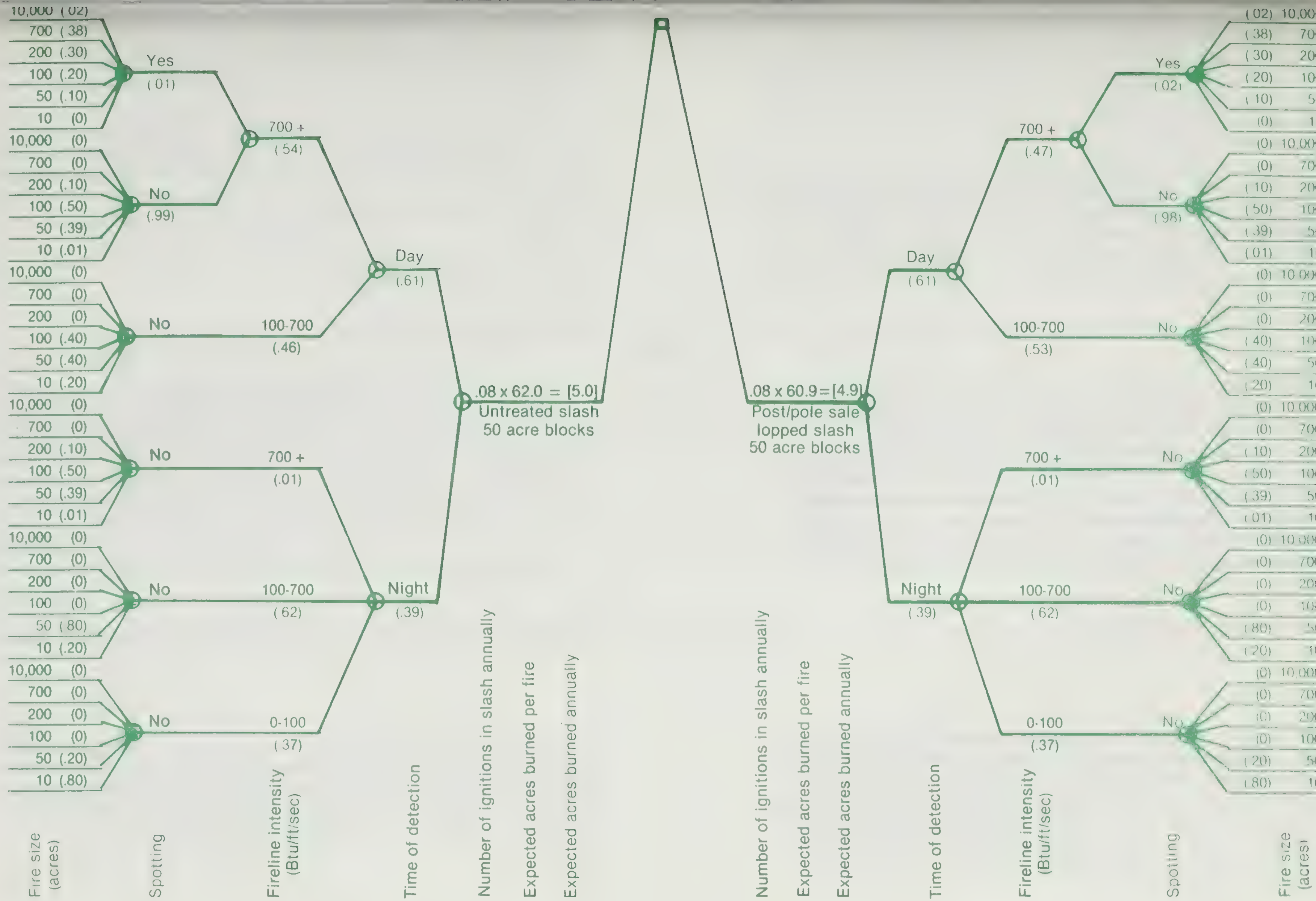
Siskiyou Step 3.—During previous years, many logged stands were broadcast burned to reduce fire hazard. However, possible damage to the very thin soil organic layer and air quality considerations are making prescribed burning less feasible. Yarding unmerchantable material (YUM) is now the favored method for treating fuels.

Fresh slash occupies only a small portion of the drainage, because only 100 acres are harvested annually. However, the effects of slash may persist for many years during the development of a new stand. Forest managers need to know how the harvesting activity affects fire hazard in the entire study area, now and in the future. They also need to know how treating the harvesting residues to different YUM standards will affect fire hazard so that an appropriate choice of fuel treatments can be made.

Three fuel treatment alternatives are considered in this analysis: (1) No modification of the slash; (2) removing all material with diameter greater than 8 inches and length greater than 10 feet (8 X 10 YUM); and (3) removing all material with diameter greater than 6 inches and length greater than 6 feet (6 X 6 YUM).



Flathead figure 1.—This decision tree summarizes the Fire Fighter Mountain fuel treatment decision analysis. The probability of an outcome (fire size) is the product of the probabilities for all branches leading to the outcome. The expected acres burned per fire for an alternative is the sum of all products of fire sizes and their respective probabilities. The expected annual number of acres burned is the product of expected acres burned per fire, and 0.08, the number of ignitions each year.



Flathead figure 1.—Continued.

Step 4: Obtain Historical Fire Records.—A data file containing the dates of past fires over a span of several years is needed. Fire occurrence data for USDA Forest Service fires since 1970 are stored in the National Fire Occurrence Data Library (Roussopoulos et al. 1980). In addition, fire history data are usually available from each regional office or other administrative unit, such as a Bureau of Land Management District Office.

To produce a reasonable fire intensity distribution, the file should have as many fires as possible for the analysis area. Depending on fire occurrence rates, enough records may be available from the analysis area itself. If not, an expanded area may be selected to supply the required data. The expanded area must have fire history and weather conditions similar to the analysis area.

Flathead Step 4.—Both the Fire Fighter Mountain area and the entire Flathead National Forest are characterized by a very low fire occurrence rate. Fire records for the 2.4-million-acre National Forest showed 529 fires between 1970 and 1975. This indicates an average rate of 0.37 fire per 10,000 acres per year (or 1 fire per 10,000 acres every 2 to 3 years). This agrees with local experience for Fire Fighter Mountain. Prorating the occurrence rate to the slash area gives (2100 ÷ 10,000 acres) × 0.37 fire = 0.08 fire per year. Historically, 61% of the fires have occurred during daytime hours (8 a.m. to 5 p.m.). These fire occurrence numbers are recorded in the decision tree (Flathead fig. 1).

A computer file of all Flathead National Forest fires from 1970 to 1975 was created for later use in step 9.

Step 5: Obtain Historical Weather Data.—A data file containing daily weather records for the same years as the fire records (step 4) is needed. Weather data are available in the National Fire Weather Data Library for all fire weather stations. Procedures for accessing these data are described by Furman and Brink (1975). The data should be from the fire weather station which best represents the weather conditions in the analysis area. Avoid choosing a station which is separated from the analysis area by a major weather-modifying feature such as a mountain range or a large lake or reservoir.

Flathead Step 5.—Weather data from Hungry Horse fire weather station (number 240217) for 1970 to 1975 were selected to represent local weather conditions. These data were stored on a computer file for use in step 9.

Fuel Modeling

Step 6: Select stylized fuel models to represent natural fuel conditions.—Fuel descriptions for all fuel conditions existing in the analysis area are required. For the natural fuels (timber, brush, and grass), select the most appropriate stylized fuel models (Albini 1976a, 1976b; Deeming et al. 1977). Some USDA Forest Service regions have localized guides for selecting appropriate fuel models.[4] Anderson[5] also discusses some of the considerations involved in matching a fuel model with a real fuel condition.

Flathead Step 6.—The uncut stand is a young, closed canopy forest. According to the down woody fuel inventory, it has a light accumulation of down fuels. There is less than 1 ton per acre of sound down woody fuel and about 9 tons per acre of rotton woody fuel. The "closed timber litter" stylized fuel model is most representative of this stand.

[4]USDA Forest Service, Southwestern Region. National Fire Danger Rating System fuel models of the southwestern United States. USDA Forest Service, Southern Region. National Fire Danger Rating System fuel models of the southern United States.

[5]Anderson, Hal E. Manuscript in preparation. Aids to determining fuel models for estimating fire behavior. USDA Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah.

Siskiyou Step 4.—Fires frequently burned throughout the study area prior to the 1900's. Most older stands were propagated by past large fires. Analysis of individual fire records indicated 142 fires occurred on the Illinois Valley Ranger District between 1970 and 1977—17.75 fires per year for the District. Prorating this rate to the study area indicates 2.06 fires per year. This analysis uses this prorated, average occurrence rate for the Illinois Valley Ranger District. Because cutting areas are already well-roaded, an increase in fire starts caused by increased cutting is not expected.

A computer file of all Illinois Valley Ranger District fires from 1970 to 1977 was created for later use in step 9.

Siskiyou Step 5.—Weather conditions within the area are best represented by data recorded at the Siskiyou Aerial Fire Depot fire weather station (number 353108) at Cave Junction, Oreg. For the 8-year period (1970-1977) used in this analysis, afternoon fire season temperatures averaged in the high eighties to low nineties. Annual precipitation was about 40-45 inches, with less than 10% falling from May to October. Windspeeds during the fire season averaged 12 miles per hour.

Weather data from this station were stored on a computer file for use in step 9.

Siskiyou Step 6.—Representation of the brush fuel conditions was based on the "low brush" stylized fuel model. Second growth and old growth fuels were represented by the "timber litter with understory" and the "closed timber litter" stylized models, respectively.

Step 7: Develop Site-Specific Activity Fuel Models to Represent the Activity Fuelbeds.—Each silvicultural action results in a unique activity fuelbed. A fuel model is needed for each fuelbed. This requirement is satisfied by use of computer program FUELBED.

FUELBED requires as input an estimate of gross debris loads. Debris from cutting activities is composed of the crowns, tops, and other unmerchantable material from the cut trees. The quantity of debris left on the site is related to the number of stems cut, type of cutting activity, tree species, tree diameter, and utilization standard. Tree weight relationships developed by Brown et al. (1977) make it possible to estimate debris loads for Rocky Mountain species from the stand table and cutting prescription (step 2). Tree weight relationships for species in other forest regions are described by Roussopoulos and Loomis (1979), Roussopoulos and Johnson (1975), Snell et al. (1980), Wartluft (1977), Loomis and Blank,[6] and Harrell.[7] Other references and examples are described in "Debris Prediction," a slide-tape training course.[8]

Some Forest Service Regions have computer programs (e.g., DEBMOD in the Northern Region) to make debris estimates. These programs read stand exam or timber sale cruise data records and directly estimate the debris loads which will result from the cutting activities.

Where a debris prediction computer program is not available or if stand data are not on computer file, debris loads can be estimated by use of tree crown weight tables (Brown et al. 1977). Figure 10 shows a crown weight table for western conifers. For program FUELBED, the debris loads must be apportioned between two fuel size classes—particles less than 3 inches in diameter and those 3 inches or larger. This is accomplished by use of a crown component fraction table (fig. 11). Table 1 demonstrates the computation of debris loads for the hypothetical stand.

[6]Loomis, Robert M., and Richard W. Blank. Manuscript in preparation. Estimating northern red oak crown fuels in the northeastern United States. North Central Forest Experiment Station, St. Paul, Minn.

[7]Harrell, R. D. USDA Forest Service, Pacific Southwest Region supplement to General Technical Report INT-37. USDA Forest Service, San Francisco, Calif.

[8]Debris Prediction is a slide-tape course developed by the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., and USDA Forest Service, Aviation and Fire Management, Washington, D.C. The course is available from the National Audiovisual Center, Washington, D.C.

In addition to the activity fuels, the existing down fuels must be accounted for. This is accomplished by estimate or by performing a down woody fuel inventory (Brown 1974). Down woody fuel loads for the hypothetical stand are shown below:

Fuel size class	Fuel load: Sound	Fuel load: Rotten
inches	------ *tons per acre* ------	
0 to 1/4	0.5	--
1/4 to 1	1.0	--
1 to 3	1.5	--
3 to 6	2.6	0
6 to 10	3.3	0
10 to 20	3.6	0
Over 20	1.8	0

The activity fuel and down fuel data are summarized for input to FUELBED as shown in figure 12. Other data, such as merchantable top standard, logging method, and slope, are also required as inputs.

Program FUELBED models the activity fuelbed 1, 3, and 5 years after the slash is created. It estimates fuel particle loadings and fuelbed depth. The FUELBED-created fuel model for 3-year-old slash in the hypothetical stand is shown in table 2. These data are stored on a permanent computer file for later use by the fire behavior computer model FIREBHV (step 9).

D.b.h. (inches)	Species PP	LP	WL-WP	DF	GF
	Pounds				
1	3.3	2.5	3.5	5.5	5.3
2	10.5	10.2	11.3	16.5	16.6
3	22.8	24.4	27.7	33.1	34.4
4	40	45	56	55	60
5	64	73	99	82	93
6	93	107	162	113	136
7	181	158	173	176	187
8	195	158	167	182	200
9	216	165	166	192	218
10	243	177	169	206	242
11	276	191	175	223	269
12	315	207	183	243	301
13	359	227	192	266	337
14	408	249	203	291	377
15	462	273	216	318	421
16	521	299	230	348	471
17	586	328	245	379	525
18	655	358	261	423	584
19	730	391	278	471	632
20	810	425	296		681
21		461	315		731
		499			783

Figure 10.—Weight per tree (pounds) by d.b.h. of all material for crowns and unmerchantable bole tips to a 6-inch top (Brown et al. 1977). Circled entries are used in table 1.

D.b.h. (inches)	Species PP	LP	WL	DF	GF	AF
2	.06	.08	.08	.06	.04	.04
4	.31	.51	.58	.38	.33	.40
6	.34	.59	.74	.46	.44	.56
8	.42	.52	.65	.46	.39	.38
10	.30	.36	.53	.33	.27	.25
12	.23	.25	.43	.24	.19	.16
14	.19	.17	.35	.18	.14	.11
16	.18	.13	.29	.14	.11	.07
18	.18	.09	.25	.11	.08	.06
20	.19	.07	.21	.09	.07	.04
22	.20	.05	.19	.07		.03
24			.17	.06		.03

Figure 11.—Fractions of crowns and unmerchantable bole tips that are 3 inches or more in diameter, for trees harvested to a 6-inch top diameter (Brown et al. 1977). Circled entries are used in table 1.

Table 1.—Debris weight computation for the hypothetical ponderosa pine stand

D.b.h.[1]	Ponderosa pine[1]		Total weight per tree[2]	Fraction of crowns and tips 3 inches and larger[2]	Slash weight[3]					
	Before cutting	To be cut			< 3 inch	⩾3 inch	< 3 inch	⩾3 inch	< 3 inch	⩾3 inch
inches	*---- trees per acre ----*		*pounds*		*-- pounds per tree[4] --*		*-- pounds per acre[5] --*		*-- tons per acre[6] --*	
1	100	50	3.3	0	3.3	0	165	0	0.08	0
4	100	50	40	0.31	27.6	12.4	1,380	620	.69	0.31
6	100	25	93	.34	61.4	31.6	1,535	790	.77	.40
10	70	35	243	.30	170.1	72.9	5,954	2,552	2.98	1.28
12	50	38	315	.23	242.5	72.5	9,215	2,755	4.61	1.38
16	30	30	521	.18	427.2	93.8	12,816	2,814	6.41	1.41
Total	450	228	--	--	--	--	31,065	9,531	15.54	4.78

[1]*Stand conditions and cutting prescriptions.*

[2]*Crown weight data transcribed from figures 10 and 11.*

[3]*Slash weights per tree are derived from the total weight and crown fraction data.*

[4]*Slash weight of ⩾3 inch material from 6 inch trees is 0.34x93 = 31.6 pounds. The weight of < 3 inch material is 93 - 31.6 = 61.4 pounds.*

[5]*Pounds per acre is the product of slash weight per tree and trees cut per acre.*

[6]*Debris load converted to tons per acre.*

Table 2.—Fuelbed characteristics for 3-year-old ponderosa pine slash for the hypothetical stand[1]

Category	Loading	Particle density	Heat content	Total ash fraction	Silica-free ash fraction	Surface area to volume ratio
	pounds per square foot	*pounds per cubic foot*	*Btu per pound*			*square feet per cubic foot*
Ponderosa pine slash						
Needles	0.1847	35.6	8,730	0.0311	0.0160	1,756
Timelag class						
1-hour	.0187	33.1	9,260	.0245	.0120	260
10-hour	.2765	30.6	8,800	.0219	.0090	90
100-hour	.2009	30.6	8,800	.0219	.0090	30
1000-hour	.2116	30.6	8,800	.0219	.0090	11
Down woody						
Timelag class						
1 hour	.0229	32.0	8,000	.0550	.0100	450
10-hour	.0459	32.0	8,000	.0550	.0100	90
100-hour	.0688	32.0	8,000	.0550	.0100	30
1000-hour	.1193	32.0	8,000	.0550	.0100	11
	.1515	32.0	8,000	.0550	.0100	6
	.1652	32.0	8,000	.0550	.0100	3
	.0826	32.0	8,000	.0550	.0100	2

[1]*Fuelbed depth is 1.44 feet; moisture of extinction is 16%.*

Run Identification *Ponderosa pine data for fuel appraisal example*
(up to 48 chartacters)

HAZARD
FUEL MOD
BED ONLY
(Enter one output indicator)

UTIL. STD. *6.0* (Enter merchantable top standard (inches); leave value blank or enter 0.0 to indicate precommercial thinning)

SKYLINE (Enter for skyline yarding)

LOP DEBRIS (Enter for for lopping to 2-foot standard depth)

MOISTURE *Use default values* (Enter 1-Hr., 10-Hr., 100-Hr., 1,000-Hr. timelag fuel moisture and duff moisture as percent)

Enter loading (tons/acre) by species and dbh class from debris prediction.

Size	Spp.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-11	11-13	13-15	15-17	17-19	19-25	25-30	30 +
– 3IN	*PP*	*.08*			*.69*		*.77*				*2.98*	*4.61*		*6.41*				
3 + IN	*PP*				*.31*		*.40*				*1.28*	*1.38*		*1.41*				
CULL																		

CULL BKG Enter only one total estimate for breakage ____

Enter loading (tons/acre) by size class from down woody inventory.

	Sound							Rotten					
Size class	0-1/4	1/4-1	1-3	3-6	6-10	10-20	20 +	3-6	6-10	10-20	20 +	Duff	Litter
DOWN FUEL	*.5*	*1.0*	*1.5*	*2.6*	*3.3*	*3.6*	*1.8*					*15.0*	

GRASS LOAD ——— Omit this card for light herbaceous fuel loads;
Enter a value of 0.0 for moderate loads;
Enter a value of 1.0 for heavy loads.

PCT. SLOPE ——— (Enter slope as a percent) *30.*

Figure 12.—Input data form for program FUELBED showing inputs for the hypothetical, ponderosa pine fuelbed. Italic entries, × 's, and circled entries are user-supplied information.

Flathead Step 7.--Tables prepared by Brown et al. (1977) were used to determine the amount of slash contributed by each tree to be cut on the Fire Fighter Mountain site. Individual tree weights for the pertinent species and size classes for the site are summarized below:

D.b.h. class	Fuel size class	Spruce	Species Douglas-fir	Larch
	inches		*pounds per tree*	
1 to 3				
	< 3	14	16	--
	≥3	1	1	--
3 to 4				
	< 3	--	--	24
	≥3	--	--	18
4 to 5				
	< 3	--	--	34
	≥3	--	--	44

To obtain the fuel loading in tons per acre, each tree weight is multiplied by 1,000 (the number of stems per acre to be cut in each species/size class) and divided by 2,000 pounds per ton. The following tabulation shows the results:

D.b.h. class	Fuel size class	Spruce	Species Douglas-fir	Larch
	inches		*tons per acre*	
1 to 3				
	< 3	7	8	--
	≥3	0.5	0.5	--
3 to 4				
	< 3	--	--	12
	≥3	--	--	9
4 to 5				
	< 3	--	--	17
	≥3	--	--	22

A down woody fuel inventory indicated an additional 10 tons per acre of fuel exists before thinning.

These data are used as input to FUELBED (Flathead fig. 2) to make a detailed model of the activity fuelbed for Fire Fighter Mountain. Although the procedure estimates fuelbed characteristics for 1, 3, and 5 years following cutting, this study assumes the third year fuelbed represents the average condition over a 10-year slash-hazard period.

Run Identification *Fire Fighter Mountain thinning*
(up to 48 chartacters)

HAZARD
FUEL MOD
BED ONLY
(Enter one output indicator)

UTIL. STD. *0.0* (Enter merchantable top standard (inches); leave value blank or enter 0.0 to indicate precommercial thinning)

SKYLINE (Enter for skyline yarding)

LOP DEBRIS (Enter for for lopping to 2-foot standard depth)

MOISTURE *Use default values* (Enter 1-Hr., 10-Hr., 100-Hr., 1,000-Hr. timelag fuel moisture and duff moisture as percent)

Enter loading (tons/acre) by species and dbh class from debris prediction.

Size	Spp	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-11	11-13	13-15	15-17	17-19	19-25	25-30	30 +
- 3IN	*ES*			*7.0*														
3 + IN	*ES*			*0.5*														
CULL																		
- 3IN	*DF*			*8.0*														
3 + IN	*DF*			*0.5*														
CULL																		
- 3IN	*WL*				*12.*	*17.*												
3 + IN	*WL*				*9.*	*22.*												
CULL																		

CULL BKG Enter only one total estimate for breakage ______

Enter loading (tons/acre) by size class from down woody inventory.

	Sound							Rotten					
Size class	0-1/4	1/4-1	1-3	3-6	6-10	10-20	20 +	3-6	6-10	10-20	20 +	Duff	Litter
DOWN FUEL	*0.1*	*0.2*	*0.2*	*0.5*				*0.2*	*1.9*	*3.7*	*2.8*	*7.5*	

GRASS LOAD .... Omit this card for light herbaceous fuel loads;
Enter a value of 0.0 for moderate loads;
Enter a value of 1.0 for heavy loads.

PCT. SLOPE .... (Enter slope as a percent) *30.*

Flathead figure 2.—Input data form for program FUELBED showing inputs for the untreated, Fire Fighter Mountain fuelbed. Italic entries, ×'s and circled entries are user-supplied information.

Siskiyou Step 7.—Estimated activity fuel loads for a typical stand in the drainage are shown below:

		Average d.b.h.		
		10	22	29
No treatment	< 3″ sound	0.5	5	23
	⩾3″ sound	.25	.4	3
	Cull	1	3	25
8 X 10 YUM	< 3″ sound	.25	2.5	11.5
	⩾3″ sound	.13	.2	1.5
	Cull	.5	1.5	12.5
6 X 6 YUM	< 3″ sound	.17	1.7	7.7
	⩾3″ sound	.08	.1	1
	Cull	.3	1	8.3

Step 8: Specify Fuel Models to Reflect Fuel Treatment Effects.—Each treated fuelbed must be represented by a fuel model. In addition, if treatments are to be evaluated over time, a series of fuel models is needed to represent the changes in fuels over time.

The effect of lopping the fuel to a 2-foot standard depth can be modeled directly using the FUELBED program (step 7). Other procedures are used for other treatments and for fuel changes over time.

The simplest procedure is to select the most appropriate stylized model for a treated fuel situation. For example, following a broadcast burn treatment for ponderosa pine slash, an area might be represented as a model for open pine stands. As another example, for western areas characterized by brush fields after logging, the brush fuel model might represent a phase of fuel dynamics of the area. Whenever possible, selecting the "best" stylized model is the recommended procedure for reflecting fuel treatments and fuel dynamics.

Where an existing stylized model is not applicable, it may be possible to modify an activity fuel model. Step 7 explained how site-specific activity fuel models are constructed. Table 2 is an example of such a fuel model. Certain fuel treatments may alter these fuelbeds in predictable ways. As an example, assume a treatment removes 50% of all 100-hour and 1,000-hour fuels; removes 25% of 1-hour and 10-hour fuels; and reduces fuelbed depth by 75%. Applying these alterations to the fuelbed in table 2 results in the fuel model shown in table 3. It is in essence a site-specific treated fuel model.

Table 3.—Simulation of the treated ponderosa pine slash fuelbed[1]

Category	Loading	Particle density	Heat content	Total ash fraction	Silica-free ash fraction	Surface area to volume ratio
	pounds per square foot	*pounds per cubic foot*	*Btu per pound*			*square feet per cubic foot*
Ponderosa pine slash						
Needles	0.1385	35.6	8,730	0.0311	0.0160	1,756
Timelag class						
1-hour	.0140	33.1	9,260	.0245	.0120	260
10-hour	.1383	30.6	8,800	.0219	.0090	90
100-hour	.1005	30.6	8,800	.0219	.0090	30
1000-hour	.1058	30.6	8,800	.0219	.0090	11
Down woody						
Timelag class						
1 hour	.0172	32.0	8,000	.0550	.0100	450
10-hour	.0230	32.0	8,000	.0550	.0100	90
100-hour	.0344	32.0	8,000	.0550	.0100	30
1000-hour	.0597	32.0	8,000	.0550	.0100	11
	.0708	32.0	8,000	.0550	.0100	6
	.0826	32.0	8,000	.0550	.0100	3
	.0413	32.0	8,000	.0550	.0100	2

[1] *The loadings were derived from table 2 as described in the text. Fuelbed depth is 0.36 foot; moisture of extinction is 16%.*

Flathead Step 8.—By specifying the LOP DEBRIS option in program FUELBED and by eliminating the greater-than-three-inch fuel loads for 4 to 5 inch diameter western larch, the fuelbed was modeled to reflect the effects of lopping to a 2-foot depth and removing post-pole materials.

Siskiyou Step 8.—The effects of YUM treatments were estimated by simply reducing the "no treatment" loadings. An administrative study of fuel treatment accomplishment on a timber sale within the drainage indicated that 6 X 6 YUM yarding removed roughly 2/3 of the loading in all fuel size classes. Therefore, the 6 X 6 YUM slash amounts were calculated as 1/3 of the no treatment loadings. No data were available for the 8 X 10 YUM situation. It was assumed that 8 X 10 YUM treatment would remove half of the fuel loading in all size classes. This reflects the opinions of the District fire staff personnel concerning acceptable accomplishment for 8 X 10 YUM fuel treatment.

Step 9: Combine Fuel and Weather Data with Fire Modeling to Produce Estimates of Local Fire Behavior.—Wildfires are more likely to start on days with certain weather conditions. For modeling fire behavior, it is desirable to use weather data only for conditions when fires are likely to occur. A fire-conditional weather file (containing weather records for fire-days only) is needed to approximate these conditions.

The computer program FIREWX creates this fire-conditional weather file by comparing the individual fire records (step 4) and the daily weather records (step 5). It converts weather observations to fuel moisture estimates and saves the records for only those days on which fires have occurred.

These fire-conditional weather data and the fuel data are combined (through Rothermel's (1972) fire model) in FIREBHV to produce localized estimates of fire behavior. The output of FIREBHV consists of cumulative probability distributions of selected fire behavior characteristics. Fireline intensity probabilities are needed in the following steps.

The user either supplies a site-specific activity fuel model (from step 7) or specifies an appropriate stylized model and topographic slope. FIREBHV then generates distributions intensity probabilities and spotting probabilities (fig. 13).

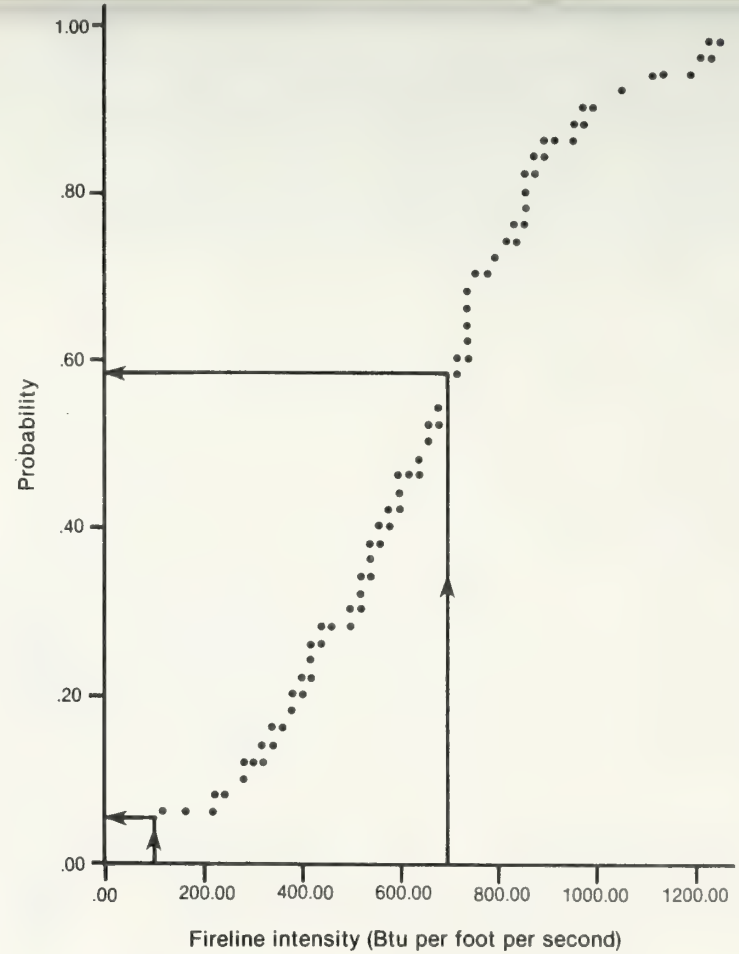
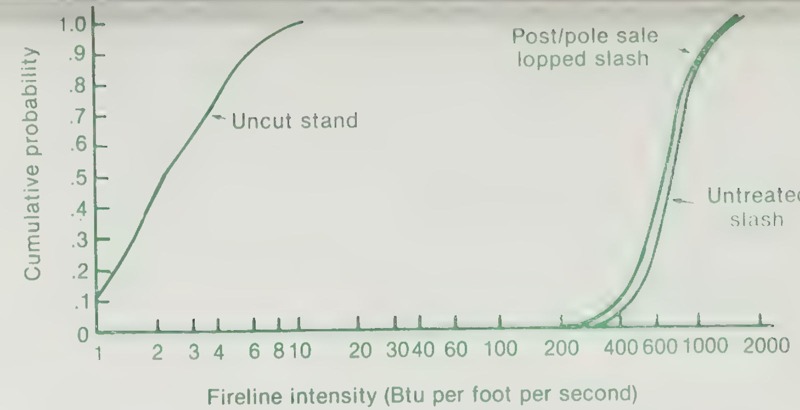


Figure 13.—A cumulative probability distribution of fireline intensity. This graph shows the levels of fire behavior which can be expected in the hypothetical, ponderosa pine slash. For example, a chance of 5% (0.05 probability) exists for a fire in the 0-100 Btu per foot per second category. For the 100-700 Btu per foot per second category, the probability is 0.53, and for a fire in excess of 700 Btu per foot per second, the probability is 0.42.

Flathead Step 9.—Flathead figure 3 illustrates FIREBHV results showing the chance that a fire in treated and untreated slash will have any specified range of fireline intensities. For the untreated slash, no daytime fire is expected to burn with an intensity of less than 100 Btu per foot per second. The probability is 0.46 that a fire will burn with an intensity between 100 and 700 Btu per foot per second, and the probability is 0.54 that the intensity will exceed 700. These numbers are entered in the event tree in Flathead figure 1. The three fireline intensity classes were selected on the basis of resistance to control considerations as described in the following tabulation (after Roussopoulos and Johnson 1975):

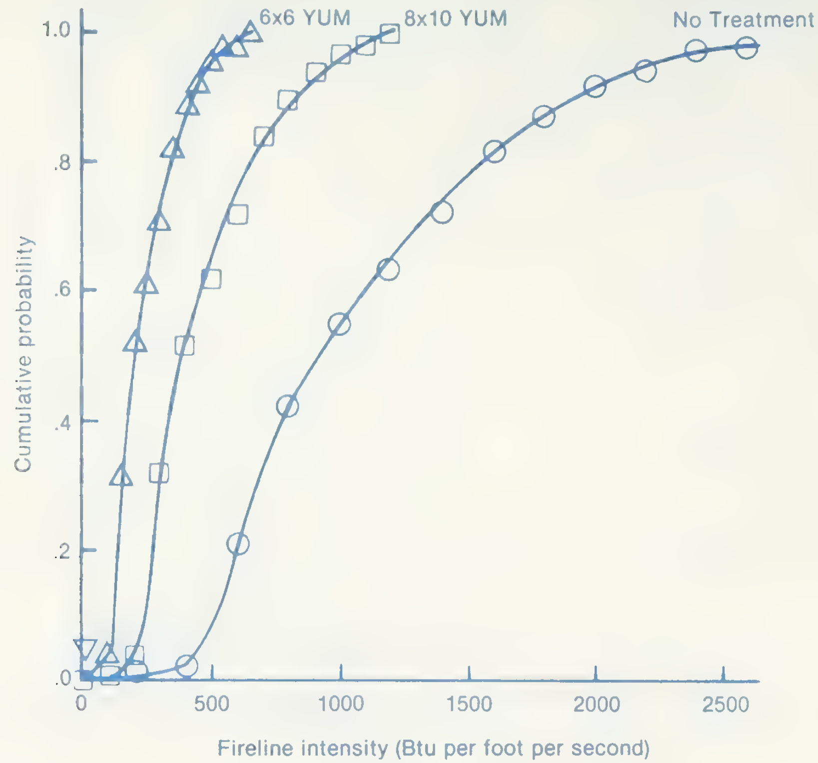
Fireline intensity	Flame length	Fire situation
Btu per foot per second	*feet*	
≤5	≤1	Marginal burning. Few fires exist at this level.
20 to 50	2 to 3	Easily attacked and controlled. People can work right up to the edge of the fire without extra protection.
100	4	This is about the limit beyond which people are unable to work at the fire edge.
500 to 700	8 to 9	Spotting begins to be a problem and the limit of direct attack is probably reached in this range of intensities.
1,000	11	Crowning can be expected to begin. Serious spotting may occur.
20,000 to 30,000	40 to 50	Major conflagration. Long-range spotting occurs. Tree blowdown may occur. Flaming zone depths of up to 1/4 mile can arise.

The FIREBHV program was run for each fuel situation using recorded afternoon and estimated night weather conditions and for spotting weather conditions. For this case study, night temperatures were estimated by subtracting mean daily temperature ranges from the recorded afternoon temperatures. Night windspeeds were assumed to be one half of the afternoon wind speeds. The resulting probabilities for fireline intensity and long-range spotting are shown in the decision tree (Flathead fig. 1). The moderate fire weather conditions typical of the Fire Fighter Mountain area make spotting quite unlikely.



Flathead figure 3.—Cumulative probability distributions showing fireline intensities for three fuelbed conditions in the Fire Fighter Mountain thinning area. The activity fuel results are for the modeled fuelbeds the third year after thinning. The uncut stand curve is for a closed timber/litter stylized fuel model.

Siskiyou Step 9.—Cumulative frequency distributions of fireline intensity were developed for each stylized fuel model and each site-specific activity fuel model. Distributions for the treated and untreated activity fuels are plotted in Siskiyou figure 4.



Siskiyou figure 4.—Cumulative distribution of fireline intensity for treated and untreated activity fuels.

Estimating Fire Size

There is no generally available analytical modeling procedure for estimating the final size at which a fire will be contained. Instead, the expert judgment of local fire personnel is used to estimate the likelihood of various final fire sizes under specified fire behavior/fuel treatment conditions. This is accomplished through a structured interview process[9] (Spetzler and Stael von Holstein 1975).

The interviewing phase is perhaps the most difficult step in the whole appraisal process. To ensure meaningful results, the interviewer must have a thorough understanding of the interview objectives and procedure. This section has been written to prepare fuels specialists for the role of interviewer in this process.

Prior to the formal interview, the interviewer and local fire expert(s) should review the fuel appraisal problem being analyzed. All local factors which have an important effect on fire size should be discussed, including: physical characteristics of the analysis area; fire suppression capability; ease of access to fires; fire suppression philosophy; land management constraints on suppression tactics (such as wilderness status); fuel types present; fire behavior characteristics; and non-fire-behavior aspects of fuel treatments (such as resistance to control). The fire expert must consider these factors when providing a fire size estimate.

In addition, the fire expert should be introduced to the general interview process and cautioned about its importance to the overall reliability of the analysis.

Even under specified conditions, final fire size is an uncertain variable. Therefore, final fire size is best expressed as a probability distribution. The distribution is constructed in two steps: (1) a set of possible fire size classes and associated average fire sizes is specified (step 10); and (2) a probability of occurrence is assigned to each possible fire size class (step 11).

[9] *A videotape illustrating this procedure is available from the Activity-Level Fire Planning Project, Rocky Mountain Forest and Range Experiment Station, 240 West Prospect, Fort Collins, CO 80526.*

Step 10: Define Possible Final Fire Size Classes.—To determine the fire size classes, the interviewer should begin with a simple line of questioning to ascertain the minimum and maximum fire sizes which could occur in the analysis area.

For example, the interviewer might ask what acreage could be burned within the analysis area if the worst possible conditions existed. "Would the entire drainage burn, or could fires be controlled after burning only a portion of the drainage?" After being satisfied that the expert has provided the best estimate of potential maximum fire size, the interviewer would ask for an estimate of a minimum sized fire. For example, "Under ideal conditions, at what size could a fire be contained?"

Between these extremes, it may be useful to consider one to three additional sizes. Perhaps an individual harvest block is a useful size to consider. Areas such as slope faces, or zones of continuous similar fuels could also be considered in selecting appropriate fire size classes. Fuel breaks, roads, major ridges, and other topographic discontinuities help define the possible limits of fire spread, and therefore also form a basis for these size classes. By carefully questioning the local fire expert, a set of fire size classes can be defined that will adequately describe the possible outcomes of a fire starting in the analysis area.

Flathead Step 10.—District fire experts were questioned to quantify their knowledge about fire size for the fire behavior situations in the decision tree. They felt the fire behavior estimates (Flathead fig. 3) indicated that fires occurring in the unthinned stand will burn with low intensity and will be relatively easy to suppress with hand tools. Fires burning in the slash will burn with very high intensity and, if not suppressed almost immediately, will be uncontrollable until they reach the slash boundary.

Although fire intensity in the unthinned stand is extremely low, a fire crossing the boundary from the slash into the unthinned stand will not immediately drop in intensity. The extreme fire behavior in the slash will cause predrying of the trees in the leave strips, making crowning likely. It is the opinion of fire experts that crowning and severe fire behavior will continue for approximately 100-150 feet beyond the slash boundary. The fire will then drop to the ground and gradually assume normal timber/litter model behavior. The sparse ground fuels and low wind velocities at the site preclude continuous crowning in the unthinned stand. Therefore, to provide a sufficient opportunity to contain most fires on the ground before encountering additional slash blocks, an uncut buffer strip should be wider than 150 feet.

Based on this fire behavior analysis, there was a strong consensus among the District fire staff that with no spotting, a majority of fires would be confined to one or two thinning blocks, but few fires would be stopped before reaching the edge of the block in which they started. There was also a consensus that fires could involve more than two blocks only under high intensity burning conditions (700+ Btu per foot per second), and spotting would be required for fires to get even larger. Most large fires would be confined to one of the 700-acre thinning units.

The above reasoning was used to define seven fire size classes with average sizes of 10, 50, 100, 200, 400, 700, and 10,000 acres. The 10,000-acre class was included to account for the possibility of a very large fire that burns the entire analysis area.

Siskiyou Step 10.—Illinois Valley Ranger District staff identified five general fire size classes which reasonably could be expected: 0-5 acres, 5-50 acres, 50-500 acres, 500-900 acres, and more than 900 acres. The mean fire size identified by district staff for each class is shown below:

Size class	Mean size
----- *acres* -----	
0 to 5	1
5 to 50	15
50 to 500	100
500 to 900	600
900 +	1000

The 0- to 5-acre class represents fires which burn under rather moderate conditions, are reached quickly by firefighters, so are contained at very small size. One thousand acres is the practical maximum size because of the broken topography within the drainage. An individual slope face in the study area typically is 600 acres, prompting the delineation of the 500- to 900-acre size class. Because cutting units in the area currently are about 15 acres, that size is used for the 5- to 50-acre class to indicate fires which burn a single cut unit. The 50- to 500-acre class represents fires which burn more than a single cut unit, but not an entire slope face.

Step 11: Assign Occurrence Probabilities to Fire Size Classes.—In this step the interviewer questions the fire expert to construct a probability distribution for the specified fire size classes. A probability is simply a numerical expression of the likelihood of an event. Probabilities can be expressed in several ways, such as ratios or percents. Expressions that are most familiar to the fire expert must be used. A probability wheel (figure 14) is one method which may be used to help the expert envision the probability situation. A linear scale is another method by which probabilities can be visually displayed.

The three hatched units above illustrate a probability which can be expressed as three chances in ten, 0.3 , or 30%. Although 10 segments are shown, any number of equal segments can be used to illustrate the desired problem.

The interviewer will describe a specific fire situation—including fire intensity, spotting likelihood, and fuel type. Each branch tip on the decision tree (fig. 4) represents a fire size outcome for a particular fire situation. The fire expert must then assign probabilities to each specified fire size for this fire situation considering local factors, such as suppression resources and access, that influence fire size. Then a new fire situation involving different fuels or fire behavior will be described and the probability assignment process repeated. This continues until fire size probabilities have been assigned for each fuel treatment alternative and fire behavior combination.

It is recommended that the fire expert first consider the probabilities of the largest and smallest fire size classes, and then to "fill in" the values for the intermediate classes. The probabilities must sum to 1.0 for each fire situation.

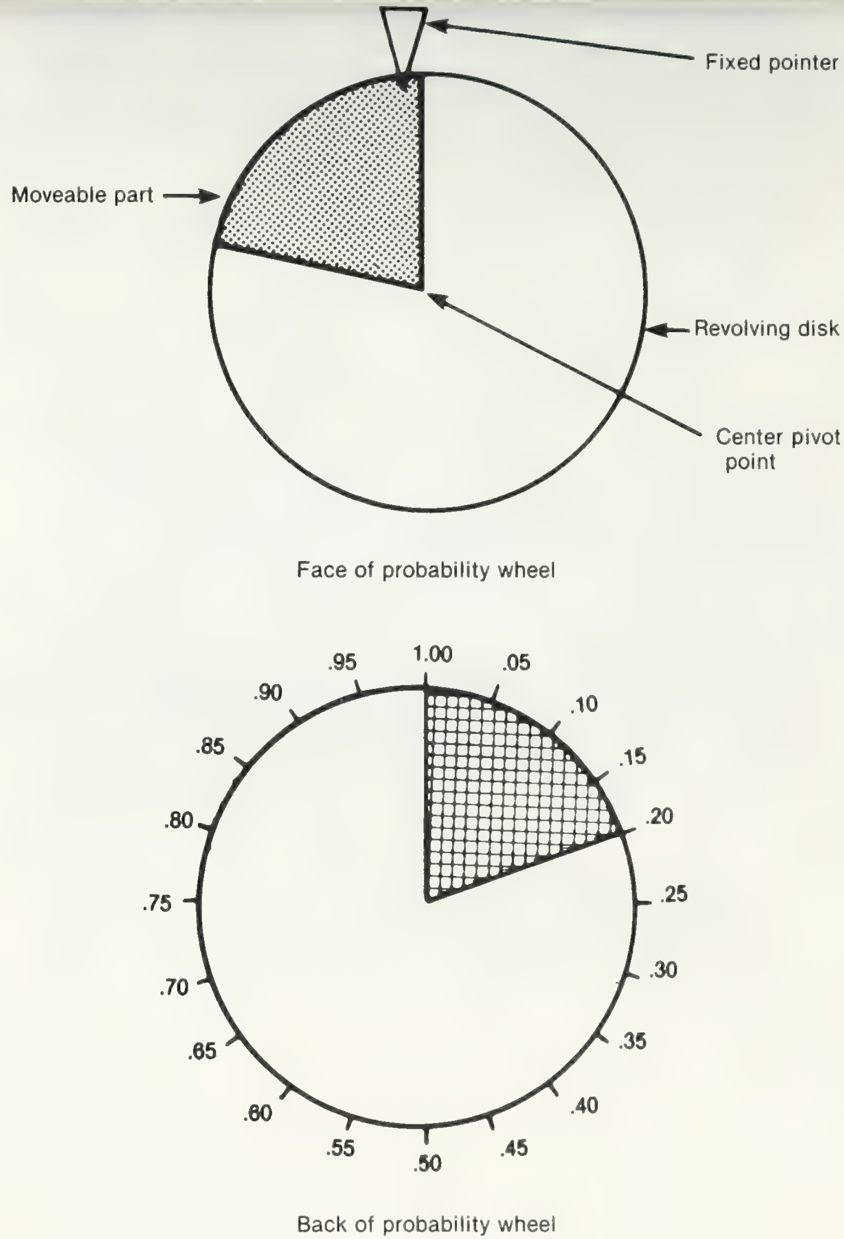
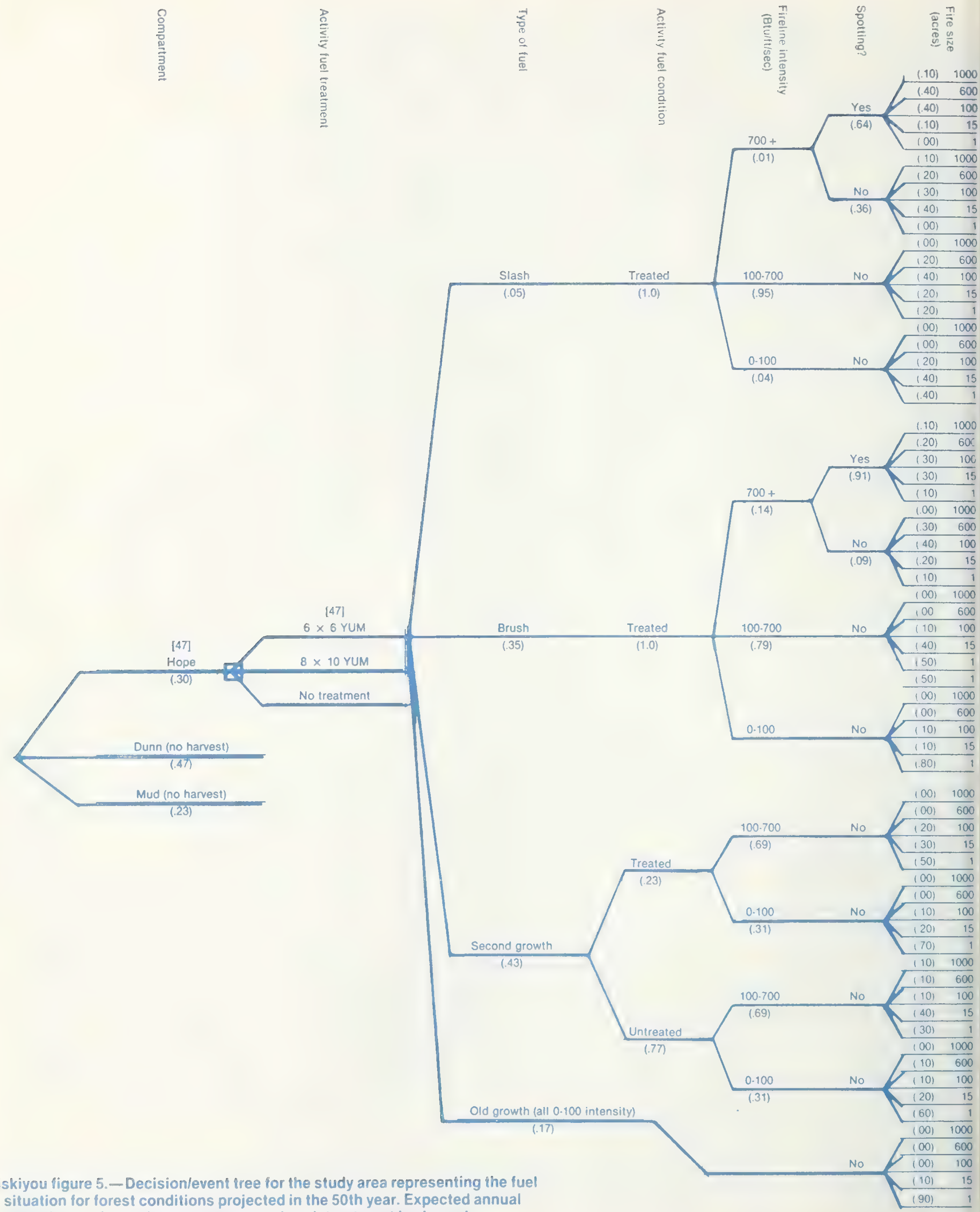


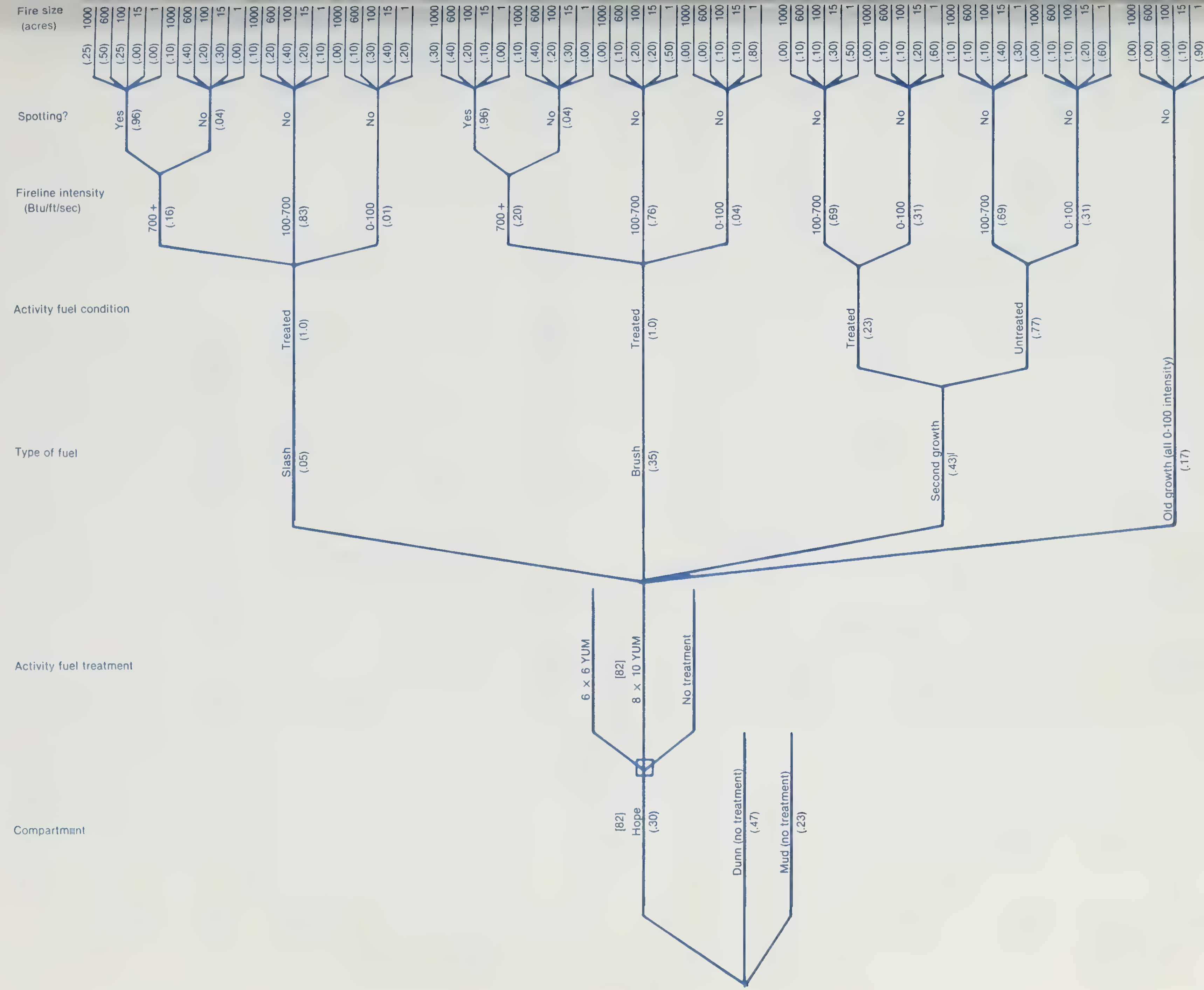
Figure 14.—Diagram of a probability wheel. The proportion of the wheel that is black is shown on the back (lower diagram). This proportion can be varied by rotating the movable face of the wheel. In this case, the probability is 0.2 (20%, or 1 chance in 5) that the black part of the wheel would stop opposite the pointer after the wheel is spun.

Flathead Step 11: Probabilities were assigned to each of the size classes for each fire behavior condition shown in the decision tree of Flathead figure 1. All probabilities are based on the assumption that present fire suppression forces will be available for future fires. A change in suppression forces might change some of the probabilities. The results of the interview appear as the final sets of probabilities in Flathead figure 1.

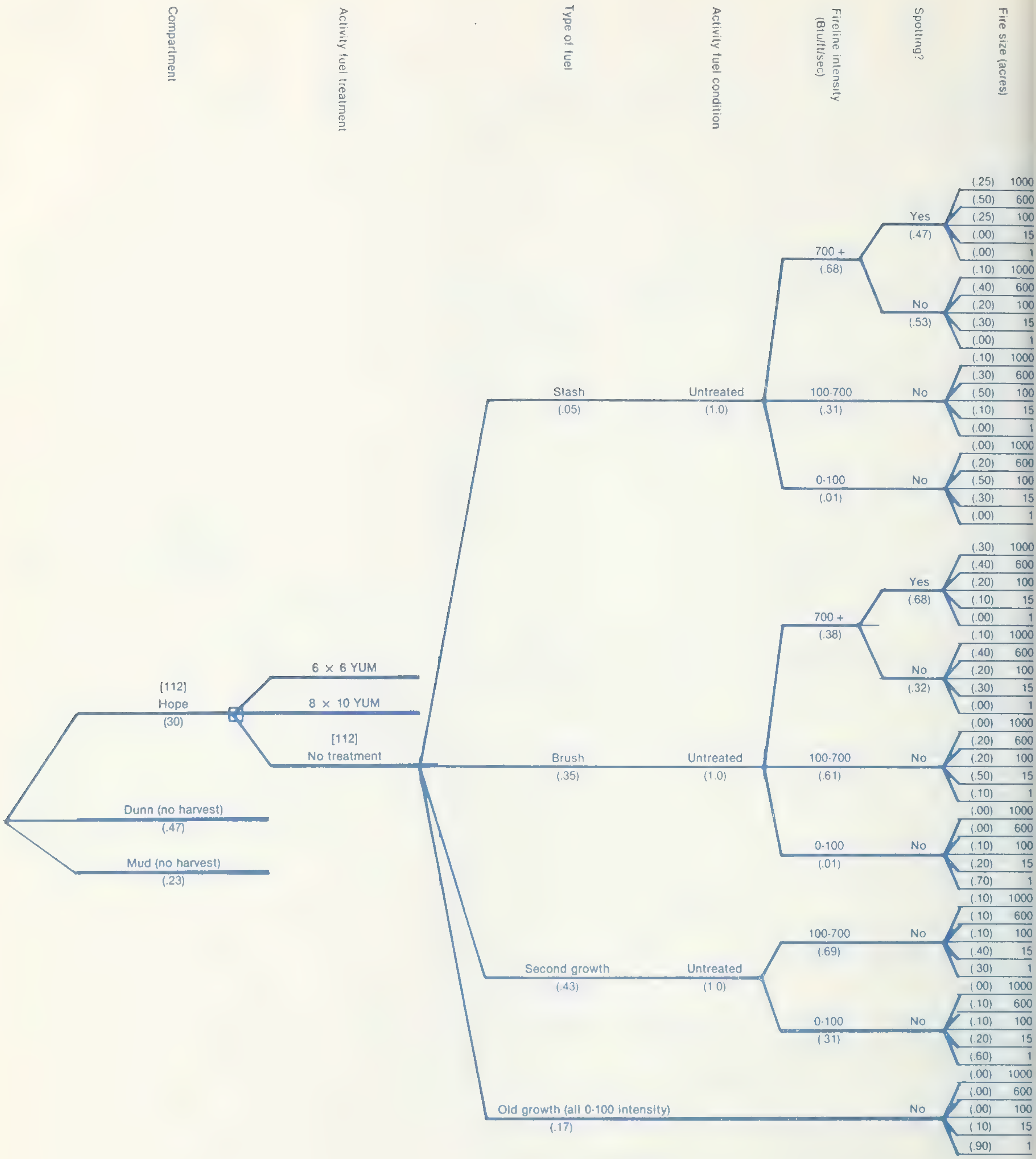
Siskiyou Step 11.—Based on local fire suppression experience, District staff assigned occurrence probabilities to each fire size class for every fire situation identified in the decision tree. An example of the results is shown in the far right column of probabilities in Siskiyou figure 5.



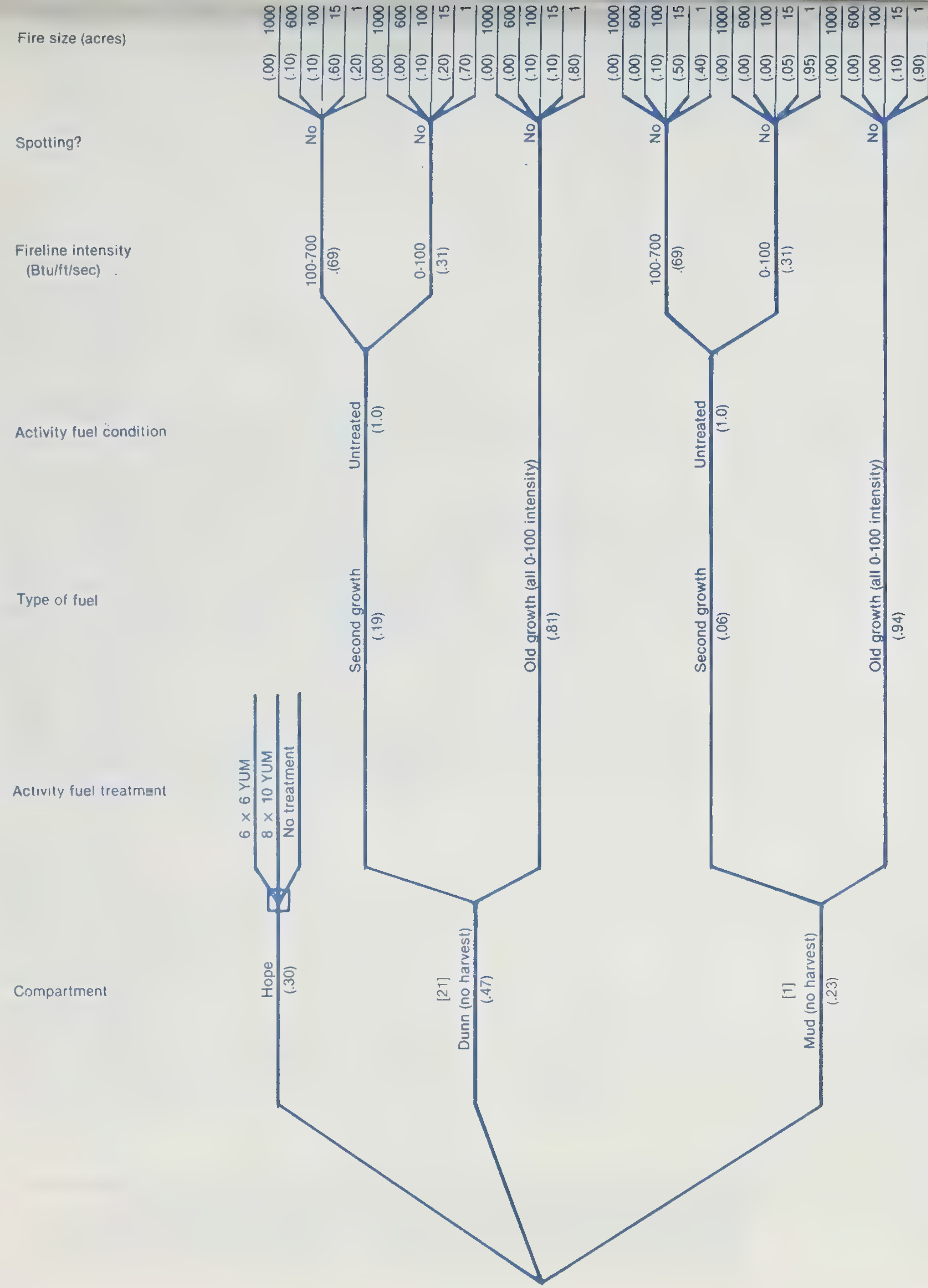
Siskiyou figure 5.—Decision/event tree for the study area representing the fuel situation for forest conditions projected in the 50th year. Expected annual burned acres for each compartment and each treatment is shown in brackets. The historical fire occurrence rate is 2.06 fires/year. The expected annual acres burned for the entire watershed with 6 × 6 YUM treatment in Hope compartment is 47 + 21 + 1 = 69 acres.



Siskiyou Figure 5.—Continued



Siskiyou Figure 5.—Continued



Siskiyou Figure 5.—Continued

Step 12: Evaluate a decision tree for each fuel treatment.—Each fuel treatment will be represented by a decision tree. An example is shown in figure 4. The specific structure of the tree will vary with the problem being analyzed.

Performing the decision tree calculations results in an estimate of expected area burned for a specific fuel treatment alternative. The results for all alternatives are compared to select the best fuel treatment.

The computer program DECTREE performs all the decision tree calculations. The user must define the tree structure and supply as input all event probabilities and outcome values. Steps 1 through 11 have made all these inputs available. A completed decision tree is shown in figure 15.

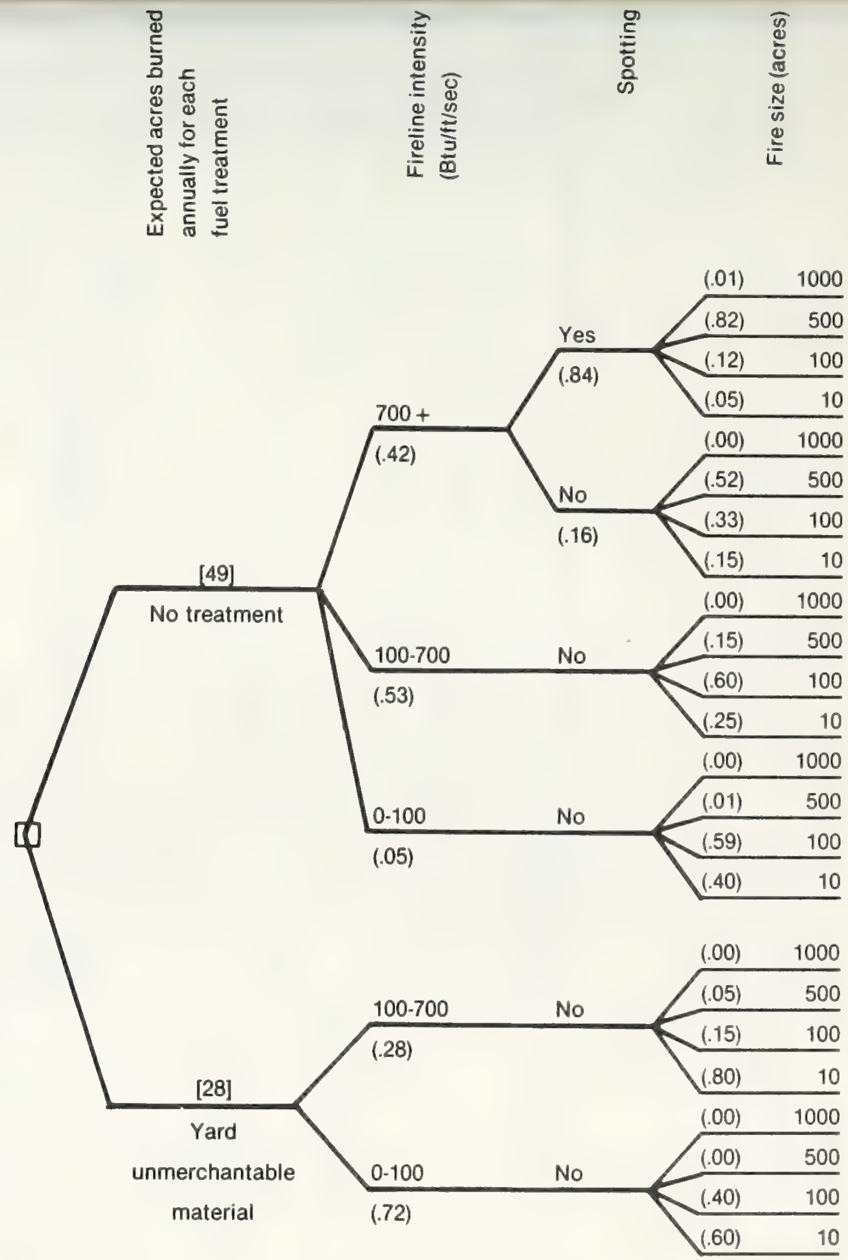


Figure 15.—Decision tree showing two treatment alternatives for the ponderosa pine slash treatment problem. The tree segment for each treatment alternative corresponds to the general tree shown in figure 4. Note that the 700 + intensity branch was not required for the "yard unmerchantable" option. In this example, fire occurrence rate is 0.6 fire per year.

Flathead Step 12.—When all probabilities were assigned in the decision tree, the fuel treatment alternatives were evaluated in terms of expected annual acres burned by program DECTREE. The expected acres burned per fire and the expected annual acres burned are shown in Flathead figure 1 for each decision alternative. The results are summarized below:

Alternative	Expected acres burned per year
100-acre blocks, no treatment	9.6 acres
50-acre blocks, no treatment	5.0 acres
50-acre blocks, lopped	4.9 acres
50-acre blocks, lopped, posts and poles removed	4.9 acres

Using the smaller block size cuts the expected loss almost in half. Because the thinning costs are about the same for either block size, the 50-acre option is recommended.

The effect of lopping is to reduce the expected annual loss by only 0.1 acre. Over the 10-year period of increased slash fire hazard, this would result in saving about 1 acre. Assuming a per-acre fire loss of $1,000, the savings would be $1,000 over 10 years. Because all 2,100 acres of activity fuel must be treated to realize this saving, the absolute maximum investment in lopping should be $0.48 per acre (using nondiscounted values). Actual costs for lopping slash far exceed this amount.

Similarly, the option of lopping with post and pole removal is not justified unless the post and pole sale provides sufficient revenue to offset its cost. Therefore, the recommended alternative is to thin in 50 acre blocks with no additional treatment.

Siskiyou Step 12.—The completed decision tree is shown in Siskiyou figure 5. This tree is more complicated than the decision tree for the Flathead case study. Probability nodes have been added to account for the three compartments and different fuel conditions within each compartment. These four additional nodes are briefly discussed below.

The compartment node shows the probability that a fire which starts within the drainage will occur in a particular compartment (Hope, Dunn, or Mud). This probability is assumed to be the fraction of the total drainage which lies within the compartment. This approximation is necessary, because detailed fire occurrence data for each compartment are not available.

The treatment alternative is selected at the treatment node. The values in subsequent probability nodes are determined, in part, by the choice at this decision node.

At the fuel type node it is assumed the probability that the fire originates in a particular fuel type is determined by the percent of the area occupied by that fuel type.

For many years after a treatment regime is begun, only a portion of each fuel type will have been treated. The fuel condition node shows the proportion of each fuel type that has received treatment.

Predicting expected acres burned as a function of time requires evaluating a decision tree for for each time interval. Siskiyou figure 5 is an example of the tree for the 50th year after a treatment regime is begun.

Each treatment alternative was evaluated at 0, 10, 30, 50, 70, and 90 years (Siskiyou fig. 6). In the first 10 years, differences in expected burned acres among alternatives are not great because only a small portion of the total harvested area has received treatment. Differences increase with time as the entire Hope compartment becomes characterized by a specific treatment option.

The no treatment alternative (Siskiyou fig. 6) results in an increase in annual expected burned acreage from 56 to 112 acres per year between year 0 and year 50. This is the result of converting old growth forest to more flammable fuel types. The 6 X 6 YUM shows a reduction in expected burn from 56 acres per year now to 47 acres per year at year 50, or 58% less burned acreage than with no treatment.

The two dashed lines show the effect of YUM treating all backlog activity fuels—in brush, second growth, and old slash—in addition to the newly created slash. This additional backlog treatment gives a 40% reduction in annual expected burned acreage during the 50th year for an 8 X 10 YUM and an 81% reduction for a 6 X 6 YUM, compared to no treatment.

For the Dunn and Mud compartments, for all years, the annual expected burn amounts are 21 acres and 1 acre. These are added to the Hope compartment figures to estimate drainage-wide expected burned acreage.

Siskiyou table 1 summarizes the expected acres burned annually by fires of different size and intensity classes for the 50th year in the Hope compartment. These estimates may be useful because the effect of fire on resources is a function of fire size and intensity. YUM treatments can have a considerable impact on resource production by reducing the largest and highest intensity fires.

YUM treatment reduction of large fires is also shown by the following comparison of the probabilities of 900+ acre fires for the three treatments (again for the 50th year in the Hope compartment):

No treatment.—P(900+) = .042 or an expectation of 1 fire every 24 years;

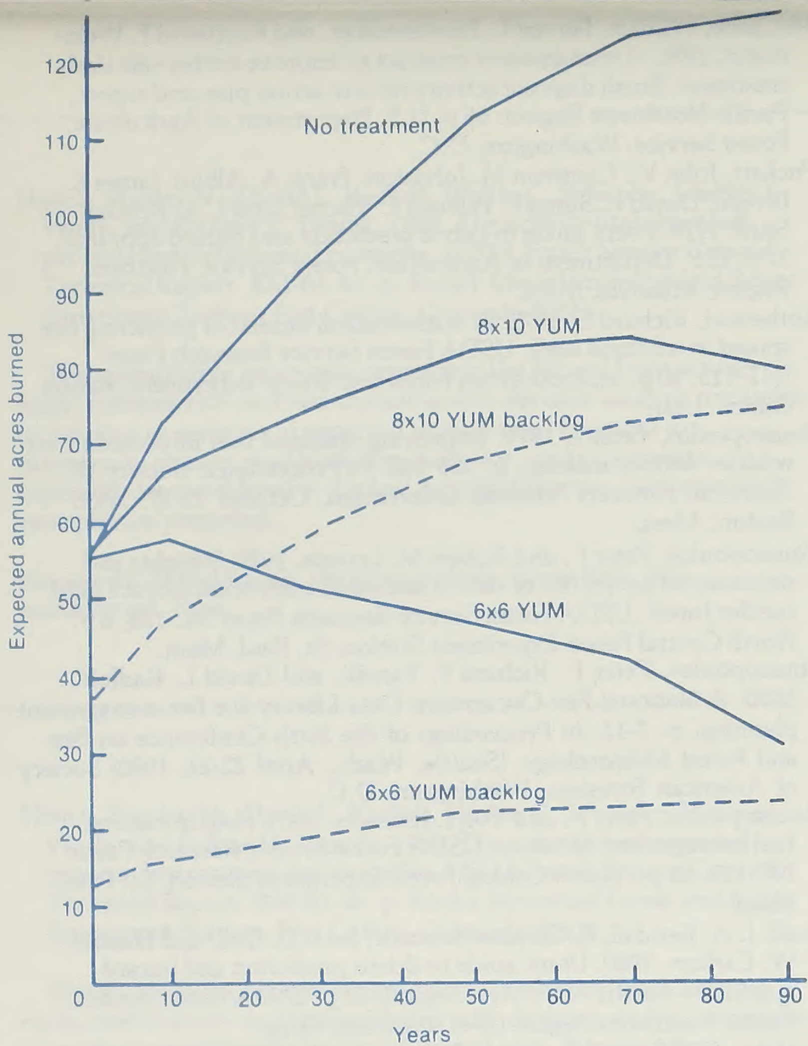
8 X 10 YUM.—P(900+) = .030 or an expectation of 1 fire every 33 years;

6 X 6 YUM.—P(900+) = .017 or an expectation of 1 fire every 59 years.

This is a useful expression of the mitigation of potentially damaging large fires by YUM treatments. In some cases the risk of large fires may be the most important consideration in selecting a fuel treatment.

Siskiyou Table 1.—Contribution to total annual expected burned acreage by fire size and intensity classes. Data are for the Hope compartment at year 50.

	Fireline intensity (Btu per ft per s)								
	0-100			100-700			700+		
Fire size (acres)	No trt	8 × 10 YUM	6 × 6 YUM	No trt	8 × 10 YUM	6 × 6 YUM	No trt	8 × 10 YUM	6 × 6 YUM
1	.2	.2	.2	.1	.1	.1	.0	.0	.0
15	.4	.4	.4	2.1	1.6	2.2	.2	.1	.1
100	.8	.9	.9	5.0	6.2	5.2	2.2	1.0	.9
600	5.0	5.0	3.8	28.6	24.1	12.0	25.4	11.9	3.9
1000	.0	.0	.0	19.4	16.7	14.1	23.1	13.9	2.8
Total	6.4	6.5	5.3	55.2	48.7	33.6	50.9	26.9	7.6



Siskiyou figure 6.—Hope compartment expected acres burned annually for the treatment alternatives.

CONCLUSIONS

The Fuel Appraisal Process provided a standardized—yet flexible—structure for analyzing diverse fuel management problems in the two case studies described. The process can help managers make systematic, documented fuel management decisions. In addition, the general decision framework presented can help managers make improved decisions in other resource management areas where uncertainty is involved.

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This quantitative process for appraising fire hazard from activity fuels combines fire- and fuel-modeling with decision analysis principles to produce an estimate of expected burned area. Expected fire occurrence, climate, fuel loads, fire behavior, and suppression capability are considered in the fuel appraisal process. Two case study examples are presented.

Keywords: Activity fuels, decision analysis, forest fires, fuel management, slash.

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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